SAN FRANCISCO

LIVING ROOF MANUAL

DRAFT FALL 2015

Special thanks

SAN FRANCISCO PLANNING DEPARTMENT
John Rahaim, *Director of Planning*
Jeff Joslin, *Director of Current Planning*
Gil Kelley, *Director of Citywide Planning*
Anne Brask
Kay Cheng
Andrew Perry
Kerby Olsen
Jon Swae
Gary Chen

DEPARTMENT OF PUBLIC WORKS

RECREATION & PARK DEPARTMENT
Hannah Schulman

SAN FRANCISCO ENVIRONMENT
Barry Hooper
Peter Brastow

SFPUC
Ken Kortkamp
Lisa Beyer
John Scarpulla
Amanda Dougherty

TECHNICAL REVIEW COMMITTEE:
Awie Smit, Habitat Gardens
Eli Zigas, SPUR
Kevin Crist, Intrinsic Landscaping
Kendra Hauser, California Academy of Sciences
Kevin Falkerson, SYMBIOSIS Ecotecture
Kerrie Lee Cole, SYMBIOSIS Ecotecture
Kirstin Weeks, ARUP
Laura Tam, SPUR
Troy Leezy, Hunter Irrigation

Photo (cover): 'California Academy of Sciences', by Kay Cheng, 2013.

ABOUT THIS MANUAL

This manual is an overview of the major policy, design, construction and maintenance issues associated with living roofs in San Francisco. Those interested in designing, installing or advocating for living roofs are highly encouraged to consult this manual for advice and guidance. This manual contains a number of recommended guidelines that will help to ensure a successful living roof in San Francisco's unique climate. This manual is not a substitute for professional design, engineering or construction advice.

SAN FRANCISCO

LIVING ROOF MANUAL

UNIVERSITY OF SAN FRANCISCO CENTER FOR SCIENCE AND INNOVATION. This living roof supports a variety of native plants, and integrates with the adjacent roof deck. The skylights let natural light into the classrooms below while also providing seating for students.

Photo: ‘University of San Francisco Center for Science and Innovation’, by Kay Cheng, 2014.

Table of Contents

The Living Roofs Manual is divided into two parts: background information on living roofs and guidelines for designing functional and thriving living roofs in San Francisco.

PART 1. BACKGROUND

APPENDIX

PART 2. DESIGN GUIDELINES

PART 1. BACKGROUND

'50 UN Plaza', Photo by Laura Kudrizki, © 2013 The Registry.

1. Introduction

Living roofs have been around for centuries, enhancing simple structures by providing a buffer from heat and cold. In recent years the understanding of the multiple ways in which living roofs benefit buildings and the environment has greatly evolved. As a result, numerous modern cities in the United States and abroad have instituted expansive living roof programs, further demonstrating that the benefits of such roofs– including improved stormwater management, reduced energy usage, habitat proliferation, and view enhancement – are substantial. These benefits are true both for individual projects, and at the city-scale.

As living roof implementation has expanded, their construction materials and technology have become more widely available and cost-effective. Living roof design and materials are adaptable to local conditions and project-specific needs. This manual intends to serve as an initial toolkit for living roof design and deployment in San Francisco, based on the technology and techniques of today. We hope that as San Francisco continues to develop more such roofs; technologies will evolve, more suppliers and implementers will participate, installation costs will further reduce, and this manual will evolve in-turn.


EcoCenter at Heron's Head Park


38 Dolores St.


1 South Van Ness


Ellis Creek Water Recycling Facility


University of California, San Francisco

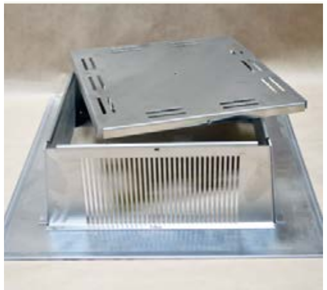
Photos (from top left to bottom right): 1. 'Heron's Head EcoCenter', Courtesy Awie Smit, 2. '38 Dolores', by Kay Cheng, 2014, 3. '1 South Van Ness', by Kerby Olsen, 2014, 4. 'Killdeer Nesting on Ellis Creek Water Recycling Facility in Petaluma, CA', by Symbiosis Ecotecture, 5. "U.C. San Francisco Ray and Dagmar Dolby Regeneration Medicine Building's living roof", by Kerby Olsen, 2015.

What is a Living Roof?

This manual uses the term "living roof" to describe rooftops that include plants and soil as an integral component of the roof. Terms used elsewhere include "green roof", "eco-roof", and "vegetated roof". The exact composition and construction of living roofs varies. Living roofs in San Francisco typically include a waterproofing membrane, a root barrier, a drainage layer, soil media, plants, and an irrigation system. Other components such as a leak detection system, a pond for wildlife, or an insulation layer may be necessary or desirable, depending on the unique conditions, goals and design of the roof. Each of the basic components and their primary functions are described briefly in this section, and in detail in later sections.

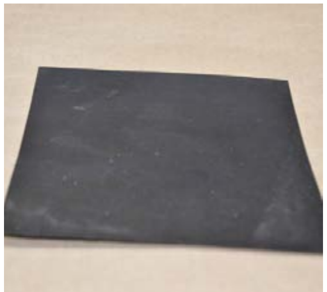
1. Waterproofing Layer

Prevents water from entering the building. Usually made of bitumen, rubber, neoprene or polyethylene, this layer needs to resist ponding, not just shed water.



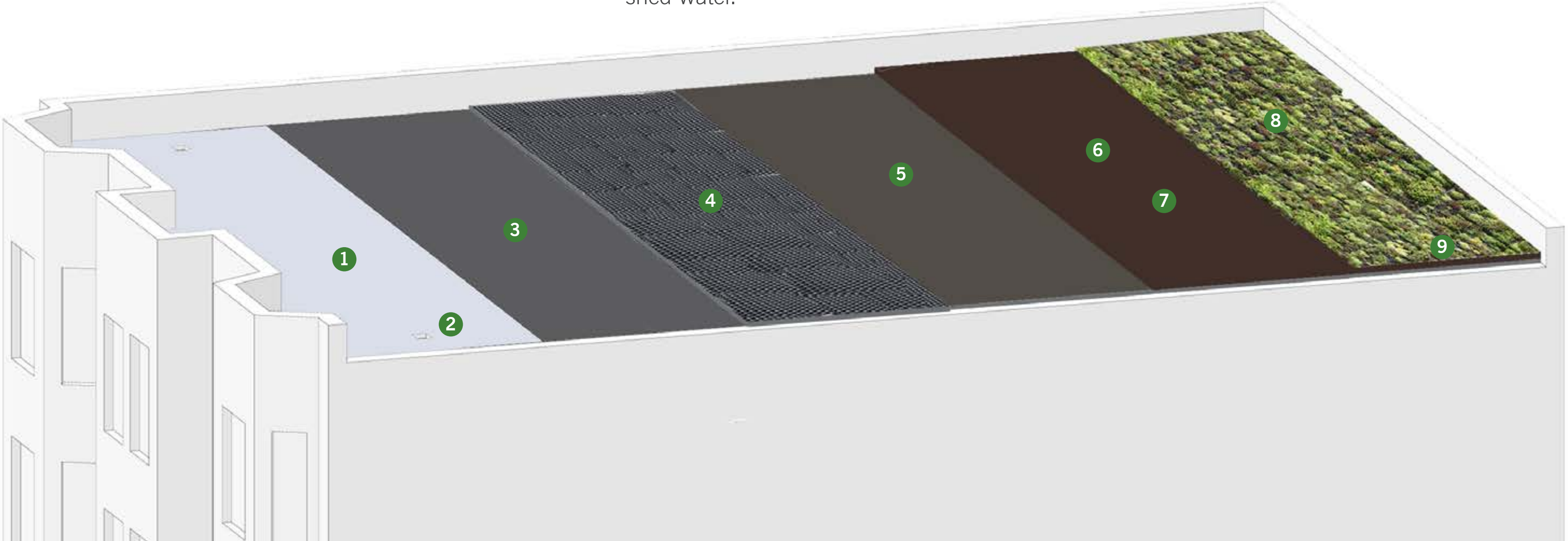
2. Roof Drain Inspection Chamber

Prevents debris from clogging drainage pipes and allows access for cleaning out.



3. Root Barrier / Protection Layer

Prevents roots from penetrating the waterproofing and protects the waterproofing layer (may not be necessary in all roofs).



4. Drainage / Retention Layer: 1-2”

Allows for water drainage and prevents ponding. May also act as water storage for plant roots. Usually composed of drain rock, absorbent fleece or plastic sheeting with depression cups which hold water.

5. Geotextile / Filter Fabric

Prevents soil media particles from passing into the drainage layer. Made of a non-rotting porous fabric, often polypropylene or polyester.

6. Soil media: 4-24”+

Provides structure and nutrients for plant roots, as well as water holding capacity. Often composed of a mix of organic matter and lightweight rock aggregate.

7. Irrigation

Keeps plants from dying or going dormant during the dry season. Usually composed of plastic drip lines, capillary mats or efficient spray heads.

8. Plants

Provide water storage, shading, air quality improvement, evapotranspiration and habitat. Often composed of drought tolerant succulents, grasses, ground covers and shrubs.

9. Edge Restraint and Vegetation-free Zone

Provides a barrier between planted areas and areas intended to be free of vegetation due to access or code requirements. Also allows drainage away from soil media to roof drains.

Photos (From top-left to bottom-right): 1. ‘Waterproofing at Heron’s Head Ecocenter’, courtesy Awie Smit, 2. ‘11” Inspection chamber’, © 2015, Green Roof Solutions, 3. ‘RB 20 Root barrier’, © 2015, Green Roof Solutions, 4. ‘Drainage panel’, © 2015, Green Roof Solutions, 5. ‘Geocomposite drain’, by Werner W Müller and Fokke Saathoff, CC BY NA 3.0, (cropped from original), 6. ‘Hoffman Bonsai Soil Mix’, by Ragesoss (Own work), CC BY-SA 3.0 or GFDL (http://www.gnu.org/copyleft/fdl.html)], via Wikimedia Commons (cropped from original), 7. ‘Drip irrigation’, photo courtesy Hunter Industries, 8. ‘Sedums’, by Kay Cheng, 9. ‘Edge restraint’, © 2015, Green Roof Solutions.

Living Roofs are a Type of "Better Roof"

Living roofs are one of a number of sustainable design approaches that take advantage of underutilized rooftop space. Solar panels, "cool" roofs, blue roofs and accessible open space each offer unique benefits and put our abundant rooftops to productive use. Living roofs and other better roof types are not mutually exclusive to each other, and many hybrid or mixed-roof types exist. For example, a building owner may choose to combine an accessible roof terrace with an intensive living roof, while installing solar panels on an inaccessible portion of the roof. This manual focuses on living roofs, which may be integrated with other better roof types as desired and/or appropriate.

Other Better Roof Types

Cool Roofs

Cool roofs, also known as "white roofs" are covered or painted with a material that reflects more of the sun's energy back into the atmosphere. These roofs are effective at cooling the building during summer months, and helping to reduce the urban heat island effect, which is partially caused by the absorption of heat by urban surfaces. White roofs are mandated for some types of new construction by the 2014 California Building Code.

Solar Roofs

Solar roofs utilize rooftop space for renewable energy production or hot water heating. Solar photovoltaic panels convert the sun's light into electricity, while solar thermal panels use sunlight to heat water for domestic use. When combined with living roofs, solar panels work more efficiently[1](due to lower rooftop temperatures) while reducing heat stress on plants by providing shading.

Blue Roofs

Blue roofs are composed of gravel or open trays which are designed to retain and slowly release the maximum amount of stormwater. New York City's Department of Environmental Protection has experimented extensively with blue roofs and found them to be effective at reducing the peak runoff from a roof during a storm event[2].

Usable Open Space

Usable open space is composed of an outdoor area designed for outdoor living, recreation or landscaping. This open space can include areas on decks, balconies, porches and roofs. Usable open space is often required in residential buildings in order to allow residents access to light and air. In commercial zoning districts, privately-owned public open spaces (POPOS) are sometimes located on rooftops, but are accessible to the public.

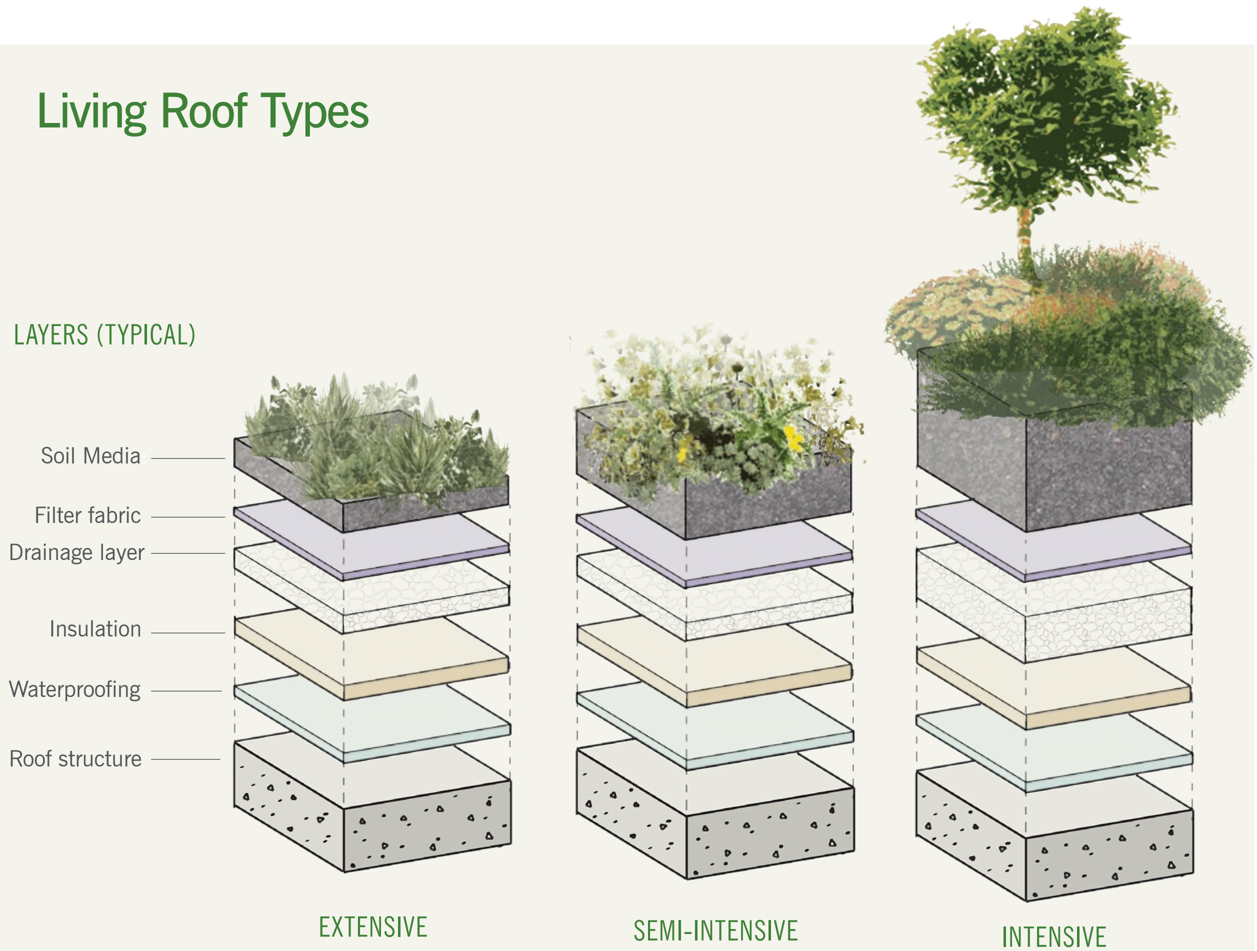
Source: 1. Lamnatou, C. and Chemisana, D. (2015). A critical analysis of factors affecting photovoltaic-green roof performance. Renewable and Sustainable Energy Reviews, (43), 264-280. Retrieved from http://www.sciencedirect.com/science/article/pii/S1364032114009794, 2. New York City Department of Environmental Protection. Retrieved from http://www.nyc.gov/html/dep/html/stormwater/green_pilot_project_ps118.shtml.

Photos (from left to right): 1. 'White roof and skylights on Las Vegas, Nev. Walmart', © 2007, Walmart Corporation, CC By SA 2.0, link to source: https://www.flickr.com/photos/walmartcorporate/5258813444/in/photostream/, (croppped from original), 2. '50 UN Plaza Solar Panels', by Kerby Olsen, 2014, 3. 'Blue Roof', courtesy Gowanus Canal Conservency.

Living Roof Types

Living roofs are classified as “extensive”, “intensive” or “semi-intensive” based on the thickness of the soil media. These three standard living roof categories have emerged because they tend to satisfy different primary goals. Intensive living roofs are often installed when the project calls for a garden-like outdoor amenity for enjoyment or agriculture. The greater soil depths of intensive systems also allow them to hold more moisture and support plants with higher transpiration rates, leading to increased stormwater capacity. Extensive living roofs are often used on larger, usually inaccessible rooftops primarily for their thermal insulation and stormwater benefits. Semi-intensive living roofs are used when a hybrid of those types is desired. The appropriate living roof type for your project will be based primarily on the structural capacity of the building, stormwater goals, the budget, and other pragmatic goals of the project.

Living Roof Types



	EXTENSIVE	SEMI-INTENSIVE	INTENSIVE
Soil Depth:	4 to 6 inches	6 to 12 inches	8 to 24+ inches
Plant Palette:	Low diversity, mainly succulents	Greater diversity, perennials	Perennials, shrubs and trees
Maintenance:	Minimal	Varies	Higher

2. Benefits of Living Roofs

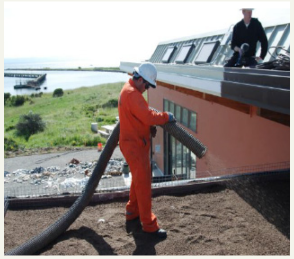
Living roofs have been shown to have many economic, social and environmental benefits. Some of these benefits accrue mainly to the building owner, and are referred to as private benefits. Other benefits accrue to the built environment and society at large, known as public benefits. Some benefits can be quantified in terms of resources or dollars (such as energy savings or stormwater retention), while other benefits are more subjective (such as biodiversity or aesthetics). Living roofs provide these many benefits simultaneously; some are readily quantifiable, others less so. A partial list of the public and private benefits of living roofs is shown on the next page.

Living Roofs Costs and Benefits in San Francisco

These costs and benefits are taken from the preliminary results of a San Francisco-specific cost-benefit analysis. The analysis is expected to be completed in Fall 2015.

270,000
Estimated total square footage of living roofs in San Francisco.[1]

$105,300
Total net present value of environmental benefits (air quality, biodiversity, heat island reduction, noise abatement) provided by San Francisco's living roofs.[2]



$31/ ft.^{2}
Average installed cost of living roofs in San Francisco, with a range of $22-76/ ft.[2] (includes waterproofing membrane).[2]

$21,151,900
Net present value of real estate benefits (value, rent, vacancy) from San Francisco's living roofs.[2]

115,125
Estimated gallons of water living roofs divert from San Francisco's sewer system each year.[3]

49%
Estimated peak stormwater flow reduction from a living roof during a 2-year, 24 hour storm.[4]

Sources: 1. Green Roofs for Healthy Cities, 2. San Francisco Living Roof Cost-benefit Analysis. 2015. , 3. Comparison of typical roof to living roof, using the "Combined sewer system BMP sizing calculator for quantity control, multiplied by total living roof area, 3. Comparison of typical roof to living roof, using the "Combined sewer system BMP sizing calculator for quantity control.
Photos (From top to bottom): 1. 'University of San Francisco Center for Science and Innovation', by Kay Cheng, 2014., 2. Construction at Heron's Head EcoCenter, courtesy Awie Smit , 3. Blue water', by Downtowngal, CC BY-SA 3.0 (cropped from original).

FOR MORE INFORMATION:

The Benefits and Challenges of Green Roofs on Public and Commercial Buildings. (2011). U.S. General Services Administration.
http://www.gsa.gov/portal/mediaId/158783/fileName/The_Benefits_and_Challenges_of_Green_Roofs_on_Public_and_Commercial_Buildings.action

San Francisco Living Roofs Cost-benefit Analysis

Public and Private Benefits of Living Roofs

	Social	Economic	Environmental
Public Benefits	**Connect people to nature ("biophilia")** – Living roofs provide opportunities to connect with the natural world in a dense urban environment. This can help reduce stress and support emotional and spiritual wellbeing. 	**Reduce stormwater overflow** – By capturing rainwater that would otherwise flow into our combined storm-sewer system, living roofs may reduce the volume of polluted overflow into the Pacific Ocean and San Francisco Bay.  	**Improve air quality & absorb pollution** – Living roofs clean the air by absorbing gaseous pollutants (carbon dioxide, sulphur dioxide, and nitrous oxide) and by capturing airborne particulate matter on leaf surfaces. **Reduce greenhouse gas emissions** – Living roofs reduce emissions associated with energy use by insulating and shading buildings. They also capture greenhouse gases by storing atmospheric carbon dioxide in plant tissue and soil. **Provide wildlife habitat** – Living roofs can provide shelter, food and nesting areas for birds and insects, including native and/or endangered species.
Private Benefits	**Create memorable and beautiful places** – The visual characteristics of living roofs (form, color, and texture) add to and enhance the aesthetics and quality of private or public open space. 	**Decrease tenant turnover/ Increase property values**– Living roofs create an attractive amenity that, in some cases, provides tenants with outdoor space. **Reduce building heating & cooling costs** – Living roofs conserve energy by shading buildings from the sun, and by serving as insulation that slows the flow of heat into or out of buildings. **Reduce infrastructure needs** – Living roofs can create multifunctional stormwater infrastructure out of an otherwise unutilized roof space. **Extend waterproofing membrane life-** Studies show living roofs may extend the life of the buildings waterproofing membrane by up to double[1].	**Decrease noise pollution** – Living roofs absorb sound and muffle noise from freeways and other sources. **Produce local food** – Fruits and vegetables can be grown on rooftop gardens, increasing food independence and reducing the distance that food must be transported to reach city dwellers. 

Sources: 1. The US General Services Administration. (2011). The benefits and challenges of green roofs on public commercial buildings, pg 64.
Photos (From top left to bottom right): 1. 'Living roof tour', by Kay Cheng, 2014, 2. 'Sewer Overflow Sign Sloat', by Tom Preet, Oceanview Bulletin (cropped from original), 3. '38 Dolores roofdeck', by Kay Cheng, 2014, 5. STEM Kitchen + Garden, by Dan Gilette, 2015.

Stormwater Retention

Before San Francisco was built, falling rainwater would land on vegetation, soil, or sand, and either be absorbed directly into the groundwater table or flow into streams and creeks and eventually make its way to the Pacific Ocean or the San Francisco Bay. Over time, urban development such as streets, parking lots and buildings replaced the natural landscape. Buildings are designed to keep water out, while streets and parking lots are designed to convey stormwater to the sewer. San Francisco is one of the only places in California in which stormwater and wastewater from homes and businesses are conveyed in the same drainage system. This type of infrastructure is known as a "combined sewer system" (CSS).

Combined Sewer System

On days with heavy rain, rainwater runoff can overwhelm the capacity of the City's three wastewater treatment facilities, leading to an overflow of the CSS. In the City of San Francisco, this is known as a "combined sewer discharge" (CSD), which happens approximately one to ten times per year[1]. During a CSD, partially treated stormwater, mixed with highly diluted effluent, discharge directly into the Pacific Ocean or the San Francisco Bay. Living roofs can help by absorbing and slowing stormwater discharge from rooftops into the CSS. The City of Portland, Oregon, found that living roofs there reduce a rooftop's stormwater discharge by between 26% and 86% over the course of a year[2].

FOR MORE INFORMATION:
San Francisco Stormwater Resources
http://www.sfwater.org/index.aspx?page=446

Low-impact Development

Living roofs are one of a number of strategies for naturally managing stormwater which are collectively known as "low-impact development". Low-impact development utilizes plants and soil to absorb and filter stormwater before slowly releasing it or re-using it for non-potable applications. Low-impact development can be a cost-effective method of distributed stormwater management, helping to reduce the burden on treatment facilities.

Stormwater Regulations

The Clean Water Act, passed in 1972, regulates the discharge of pollutants into surface waters of the United States, including Oceans, bays, rivers and lakes. This act also grants the authority to regulate non-point sources of pollution, such as runoff from impervious surfaces, to local jurisdictions. As a result, San Francisco has enacted the Stormwater Management Ordinance for new development projects. The required stormwater management controls depend on the project size, location and type. See the San Francisco Stormwater Design Guidelines for more information.

San Francisco stormwater drainage districts
Reproduced from San Francisco Stormwater Design Guidelines

Energy Savings

Living roofs save energy by reducing building heating and cooling demand in a variety of climates. The soil component of living roofs provides insulation that reduces heating demand, while the leaf surface of the plants provides cooling through evapotranspiration and shading, reducing air conditioning demand. The overall building energy performance of living roofs improves with increasing soil depth and

1. City and County of San Francisco 2030 Combined Sewer System Master Plan (2009). 2. City of Portland. Cost Benefit Evaluation of Ecoroofs (2008).

vegetative cover[1]. However, the magnitude of energy savings varies greatly based on local environmental conditions, the details of the roof, other specific building factors such as the roof area to building volume ratio, and the baseline conditions used for comparison[2]. The accompanying table reflects the results of example energy savings calculations for two hypothetical San Francisco living roof designs, as indicated.

1. Sailor, Elley and Gibson. (2012). Exploring the building energy impacts of green roof design decisions – a modeling study of buildings in four distinct climates. Journal of Building Physics. vol. 35 no. 4 372-391

2. The Portland State Green Building Laboratory publishes an interactive, online “Green Roof Energy Calculator”, which allows for simulation of the energy savings from living roofs in various climates. This calculator was used to estimate energy savings of several hypothetical living roofs in San Francisco, one 10,000 square foot commercial roof, and one 2,000 square foot residential roof.

Example Energy Savings Calculations

	NEW CONSTRUCTION		RETROFIT	
	Commercial	**Residential**	**Commercial**	**Residential**
Energy savings ($/year)	**$268**	**$63**	**$540**	**$186**
Energy savings (%)	4.8%	.8%	6.2%	1.1%
Building size (ft.^{2})	10,000	2,000	10,000	2,000
Living Roof Coverage	80%	80%	60%	60%
Soil media depth	8”	8”	6”	6”

Photos (From left to right): 1. ‘38 Dolores roof’, by Kay Cheng, 2014, 2. ‘Matarozzi Pelsinger living roof’, by Kay Cheng, 2014.

3. Permitting and Code Compliance

Building a living roof in San Francisco almost always requires permits. Depending on the unique conditions and design of the roof, it may require the involvement of multiple permitting agencies. In broad terms, the Department of Building and Inspection will review the design for code compliance, the Planning Department will determine if the project complies with the City's General Plan, and the Public Utilities Commission will review the design and sizing if the project triggers the stormwater management ordinance (SMO).

The Planning Information Counter (PIC)

Planning Department

The Planning Department will check the building permit application to determine if any discretionary action is needed, such as neighborhood notification or a public hearing. If not, they may issue a planning permit over-the-counter. If a discretionary action is needed, a Planner will assist with the process. After building permits are approved, The Living Roof Declaration Form (Appendix B) should be submitted to them for data collection. Bring the application the Planning Information Counter (PIC) to determine if the project is in accordance with City Codes and the General Plan.

FOR MORE INFORMATION:

San Francisco Department of Building Inspection
http://www.sfdbi.org

San Francisco Public Utilities Commission
http://www.sfwater.org

San Francisco Planning Department
http://www.sf-planning.org

Department of Building and Inspection (DBI)

The Department of Building and Inspection is the primary permitting department responsible for issuing residential and commercial building permits, including new construction and re-roofing permits. They verify that living roofs are safe, meet all of the relevant building and fire code requirements, and are well-constructed. Applicable permits may include a plumbing permit for the irrigation, a building permit for the construction, a fire permit, a structural permit, and an electrical permit for any lighting or electrical outlets. Permits, inspections and fees originate from this agency.

Public Utilities Commission (PUC)

The PUC may be involved in the design of a living roof if it is proposed for compliance with the SMO. Projects triggering compliance with the SMO must submit a stormwater control plan (SCP). The PUC will review the SCP, verify the living roof's design, and review the operations and maintenance (O+M) plan. The PUC will require annual self certifications of the living roof to ensure effective long-term stormwater management. This review and approvals process runs parallel to the DBI's permitting process.

Applicant (you)

The applicant is responsible for designing a living roof that meets all applicable code requirements, preparing building plans, submitting the plans for approval, and paying all applicable permit fees. Professional designers or contractors may represent the building owner during portions of the permitting process. After construction is approved, the applicant is responsible for constructing and maintaining the living roof.

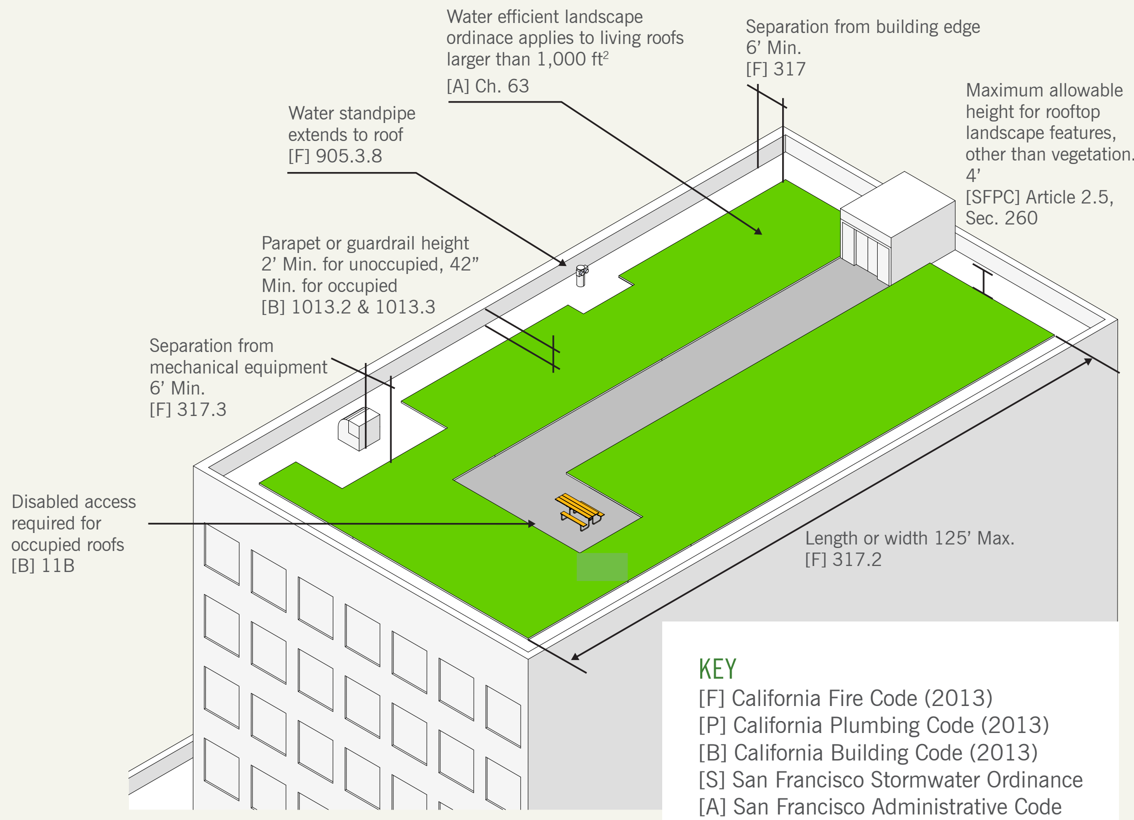
Permit fees

Permit fees will be assessed by the departments that are responsible for reviewing the project, and will vary by project type, construction cost, and hours required to review the plans. These fees are subject to change; see the department's websites for current fee schedules.

Example

This code compliance illustration visually depicts some of the code requirements that may be applicable to a newly-constructed living roof on a commercial building that is accessible to occupants and includes outdoor amenities. This type of roof will require provisions for ingress and egress, mechanical equipment separation, disabled access, and a water standpipe. Other code requirements, not depicted, also apply.

Example Code Requirements



KEY
[F] California Fire Code (2013)
[P] California Plumbing Code (2013)
[B] California Building Code (2013)
[S] San Francisco Stormwater Ordinance
[A] San Francisco Administrative Code
[SFPC] San Francisco Planning Code

Permit Process Flow-chart

This flow chart is intended to illustrate the general process for obtaining permits and approvals for living roofs in San Francisco. While not exhaustive, this chart contains the primary permitting steps, as well as the basic processes of the responsible permitting or approvals agencies. Permitting requirements are highly project-specific, therefore it is recommended to visit the Department of Building Inspection information desk at 1660 Mission st. or call (415) 558-6088 during the initial design phase, to understand what is allowed.

1. INITIAL DESIGN

Review the Living Roof Manual and Recommended Guidelines for Living Roofs (Appendix A). Visit or call the DBI information desk. Determine project goals and objectives. Complete initial living roof design.

2. DETERMINE RESPONSIBLE AGENCIES

The agencies responsible for reviewing or approving your living roof will depend on its size and type.

NEW CONSTRUCTION

START HERE

Have a licensed design professional (LDP) estimate the loading capacity of the proposed roof and ensure that it is greater than the estimated weight of the living roof.

?

Does the project trigger the SF PUC stormwater management requirements per the SMO?

YES

NO

!

The living roof may help comply with this requirement. See the SF PUC's **Stormwater Design Guidelines** for more information.
www.sfwater.org/sdg

RETROFIT

START HERE

Have a licensed design professional (LDP) investigate the structural integrity of the roof and estimate the existing loading capacity. Ensure that the living roof can be supported, in addition to other live loads.

?

Does the living roof cover greater than 25% of the building roof area or require installation, repair or removal of the roof sheathing or any new plumbing or electrical work?

YES

NO

Take the proposal to the Department of Building Inspection information desk at 1660 Mission to obtain the proper permit applications, pay application fees and begin the permitting process.

Building permits may not be needed

Check with the DBI to be sure.

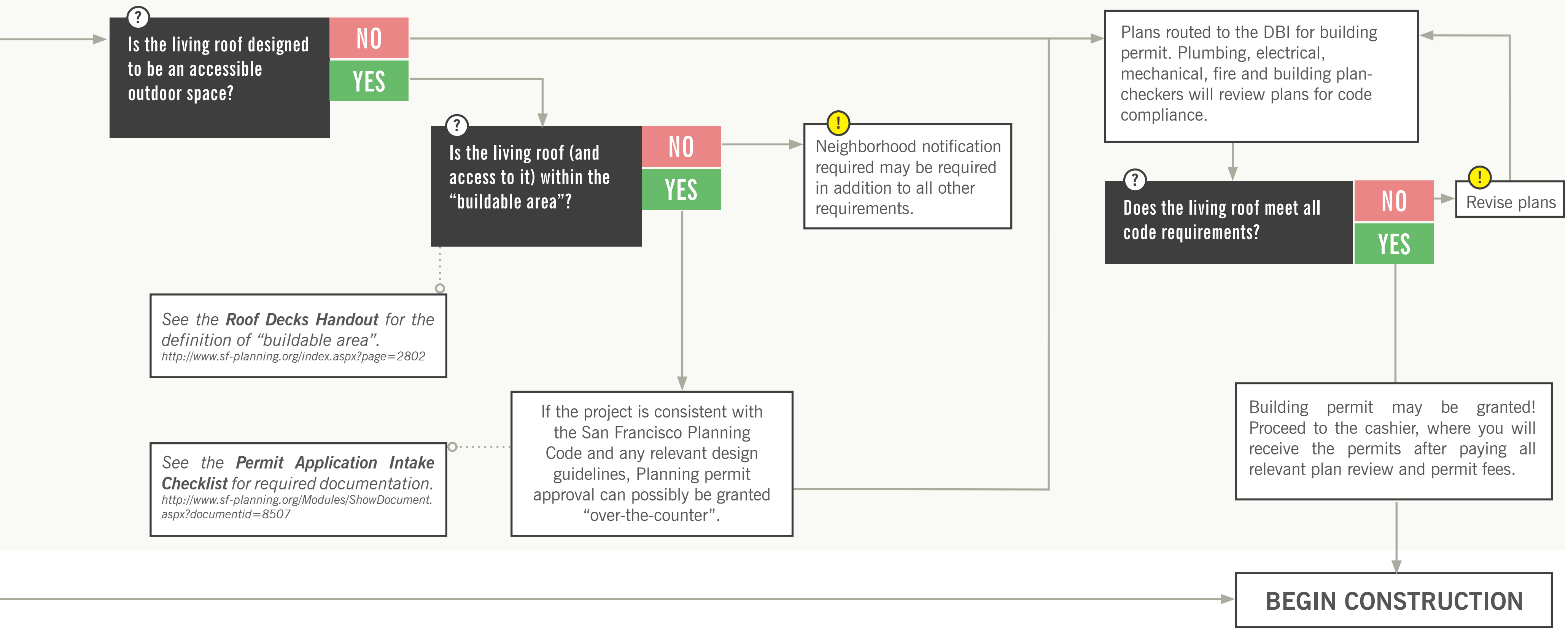
Sources: San Francisco Department of Building Inspection. (2007). How to obtain a building, electrical, plumbing permit for the remodeling of single and two family dwellings in the City and County of San Francisco. p 7. Rretrieved from http://sfdbi.org/sites/sfdbi.org/files/migrated/ftp/uploadedfiles/dbi/Key_Information/19_HowToObtainPermit1006.pdf

3. PLANNING DEPARTMENT REVIEW

The Planning Department's involvement will vary based on the roof's accessibility and weather it fits inside the "buildable area" of the building. Additional restrictions may apply to designated historic buildings.

4. DEPARTMENT OF BUILDING INSPECTION

The DBI will take the approved plans from the Planning Department and ensure compliance with all relevant codes, issue the building permit and charge the permit fees.



4. Design

Living roofs, like the buildings they cover, are highly variable, and each project will call for a unique design. This chapter is intended to give an overview of how one should approach the design process as a whole.

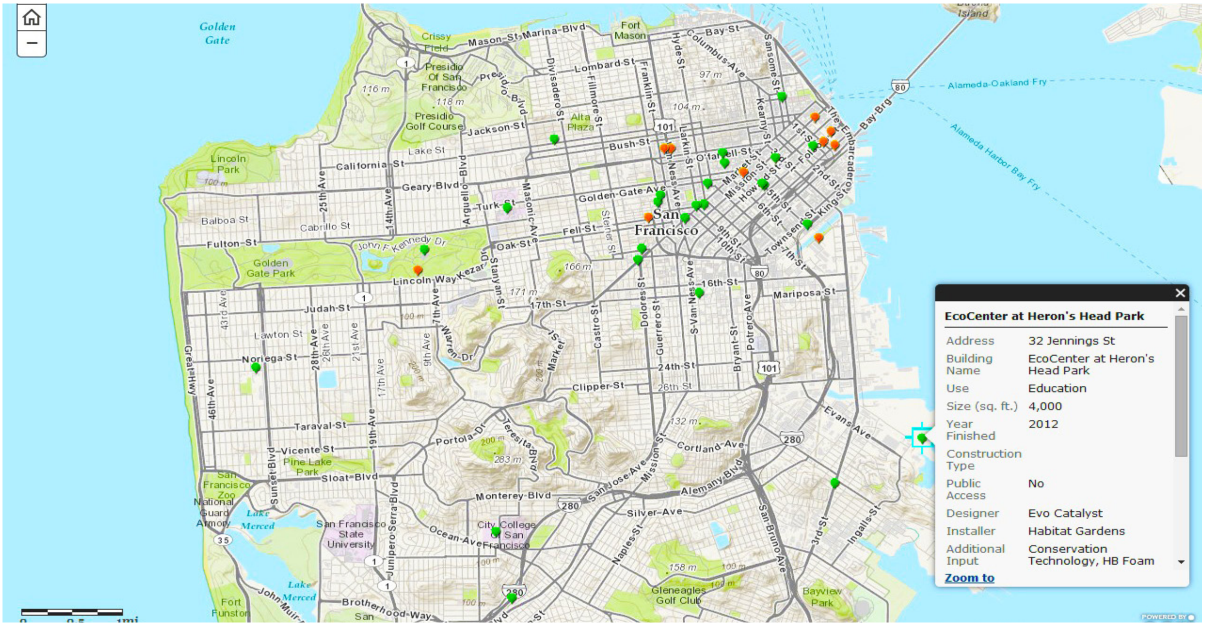
1. Site Visits and Education

A great place to begin is through education and site visits. For more detailed discussion of topics discussed in this manual, refer to the resources listed in the boxes in the bottom left of each chapter. San Francisco is home to several excellent living roofs that are open to the public. These roofs can be located through the Living Roof Map and Database on the Planning Department's website. Visiting these roofs can give you a sense of what can be achieved on your project.

2. Finding a design professional

Assembling a great design team will help ensure a successful living roof project. Although living roof design is similar to the design of other building and landscape elements, it is recommended to retain at least one design professionals with living roof experience. The integrative nature of living roofs means that multiple design professionals will need to work together across disciplines to coordinate a successful project.

Green Roofs for Healthy Cities (GRHC) is a not-for-profit industry association working to promote living roofs. GRHC provides accreditation for professionals who have completed education and examination in the design and installation of living roofs (known as "green roof professionals" or GRPs). GRHC maintains a searchable list of accredited GRPs on their website.



The San Francisco Living Roof map can be used to find out about living roofs near you.

FOR MORE INFORMATION:

Green Roofs For Healthy Cities. Green Roof Professionals.
http://www.greenroofs.org/index.php/membership/findagreenroofpro

San Francisco Living Roof Map and Database
http://www.sf-planning.org/livingroof

3. Determine project goals and objectives

Once you are familiar with the basics of living roofs and have found a design professional to work with, the process of designing the living should begin by determining the project's goals and objectives. Living roofs have many benefits, so it will be useful to identify which benefits will be most advantageous to the project, and maximize those benefits as much as possible. For example, on some projects, a living roof may be the only space-efficient way to reduce stormwater runoff. On other projects, a living roof might be a key amenity that will lure prospective tenants or provide habitat for a local butterfly species

Designer roles and responsibilities

Each discipline of the project team will provide a unique contribution to the design of the living roof. Cross-discipline communication is important, for example: the mechanical, electrical and plumbing (MEP) components on the roof should be communicated to the living roof designer. This way, the living roof components can be designed to work around the mechanical components, and the necessary edging materials can be specified. The size of the design team will vary based on the size and scope of the project. The roles and responsibilities of potential team members are described below.

Architect

The architect may act as the leader of the design team, particularly for new construction, coordinating the project to ensure that the roof is well integrated with the rest of the building. The architect will also be responsible for the interface between the living roof and other building components, as well as aspects of permitting and cost estimation.

Structural Engineer

The structural engineer will assess the structural capacity of the roof, determine the loads associated with the living roof and other rooftop components, and design the roof's structural support accordingly. The structural engineer may also plan for how materials will be transported to the roof and distributed.

Awie Smit of Habitat Gardens explains the design of 50 UN Plaza's living roof. Photo by Anne Brask, 2014.

Landscape Architect

The landscape architect will help to design the components of the living roof above the waterproofing membrane, including the drainage, soil media and planting plan. The landscape architect may also design the irrigation system, or defer that component to an irrigation specialist. This role may also be carried out by the living roof consultant.

Civil Engineer

The civil engineer will work with the architect to calculate stormwater runoff, meet stormwater management requirements and design a drainage system to manage the expected stormwater.

Roofing Consultant

The roofing consultant will help to design the roofing details of the project, and specify an appropriate waterproofing layer.

Living Roof Consultant/ Green Roof Professional

The living roof consultant will help to detail the living roof components and planting plan. They can also identify what benefits are to be achieved and which ones are to be emphasized by the living roof; have industry knowledge related to selecting the best performance system for the given project type and condition; and develop the proper construction sequence.

5. Case Studies

Living roofs in San Francisco often fall into one of four typologies, depending on their primary objectives: research and education, urban agriculture, habitat and ecology, or stormwater management. However, most projects will incorporate elements from several typologies. Four case studies are explored in this chapter in order to give insight into the design, benefits, and issues associated with each typology. Additional case studies are available on the Planning Department's Living Roofs website: sf-planning.org/livingroof

Habitat + Ecology

Heron's Head EcoCenter

Research + Education

California Academy of Sciences

Stormwater Management

1 South Van Ness

Urban Agriculture

STEM Kitchen + Garden

Photos (From left to right): 1. 'Heron's Head EcoCenter', by Kay Cheng, 2013, 2. 'California Academy of Sciences weather startion', by Kerby Olsen, 2014, 3. '1 South Van Ness', by Kerby Olsen, 2014, 4. STEM Kitchen + Garden by Dan Gilette, 2015.

Photos: '1 South Van Ness Living Roof', by Kerby Olsen, 2014.

HERON'S HEAD ECOCENTER

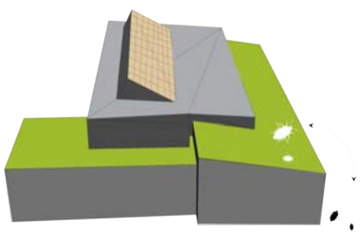
Year: **2010**

Type: **Semi-intensive**

Access: **Not for public**

Living Roof System: **Built-up layers**

Designed by: **Evocatalyst and Habitat Gardens**



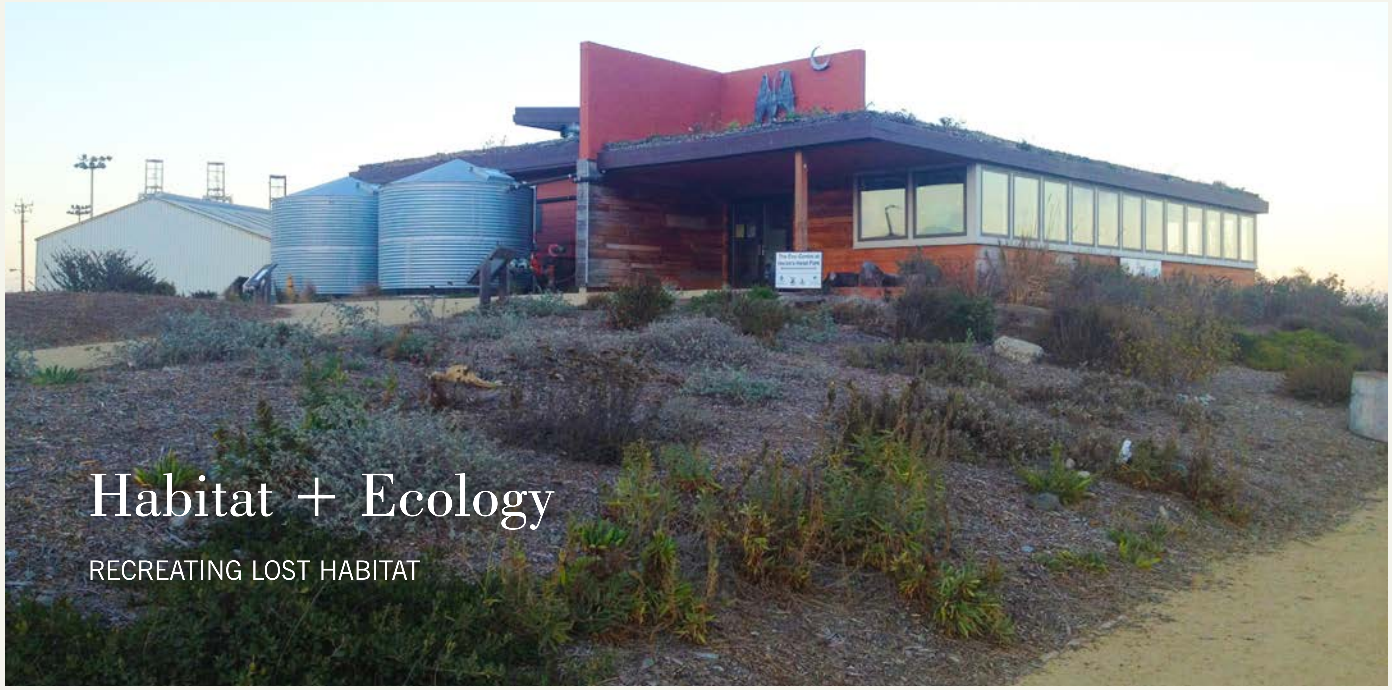


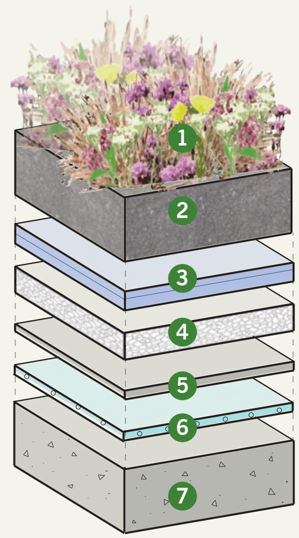
Photo by Kay Cheng, 2014.

PROJECT BACKGROUND

This former toxic dumping ground is now an environmental education center and native species habitat. The Heron's Head EcoCenter incorporates multiple sustainable design strategies, including: an off-grid solar array, on-site blackwater treatment system, 15,000 gallons of rainwater storage, riparian wetlands, vegetative roof, and native landscape.

Heron's Head EcoCenter is a habitat restoration project for plants and animals in an industrial, urban environment. Only Bay Area native plants are used in the landscaping and living roof, as they require less water and are adapted to local soils.

The roof's parapet is layered with materials that plants and animals can call their home, such as logs, rocks, and shells. This material palate was inspired by the surrounding beach ecosystem. Larger rocks and sticks provide shade and shelter, while a small wetland provides habitat and plays an important role in several species' life cycles. The Heron's Head EcoCenter is a great example of how a living roof can reduce the environmental impact of development by restoring habitat on top of the building.



ROOF SECTION

1. Native Plant Species
2. Soil Media (Scoria, coarse sand, organic matter)
3. Subsurface Drip System
4. Lava Stone / Pumice Rocks
5. Capillary Mat
6. Monolithic Urethane
7. Building Concrete

CALIFORNIA ACADEMY OF SCIENCES

Year: **2007**

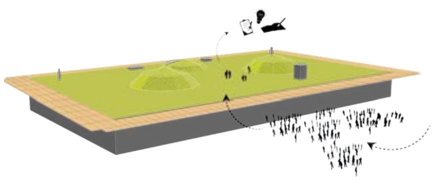
Type: **Semi-intensive**

Size: **197,000 sq. ft. (2.5 acres)**

Access: **Public access from museum observation deck**

Living Roof System: **Bio-trays**

Designed by: **Rana Creek**



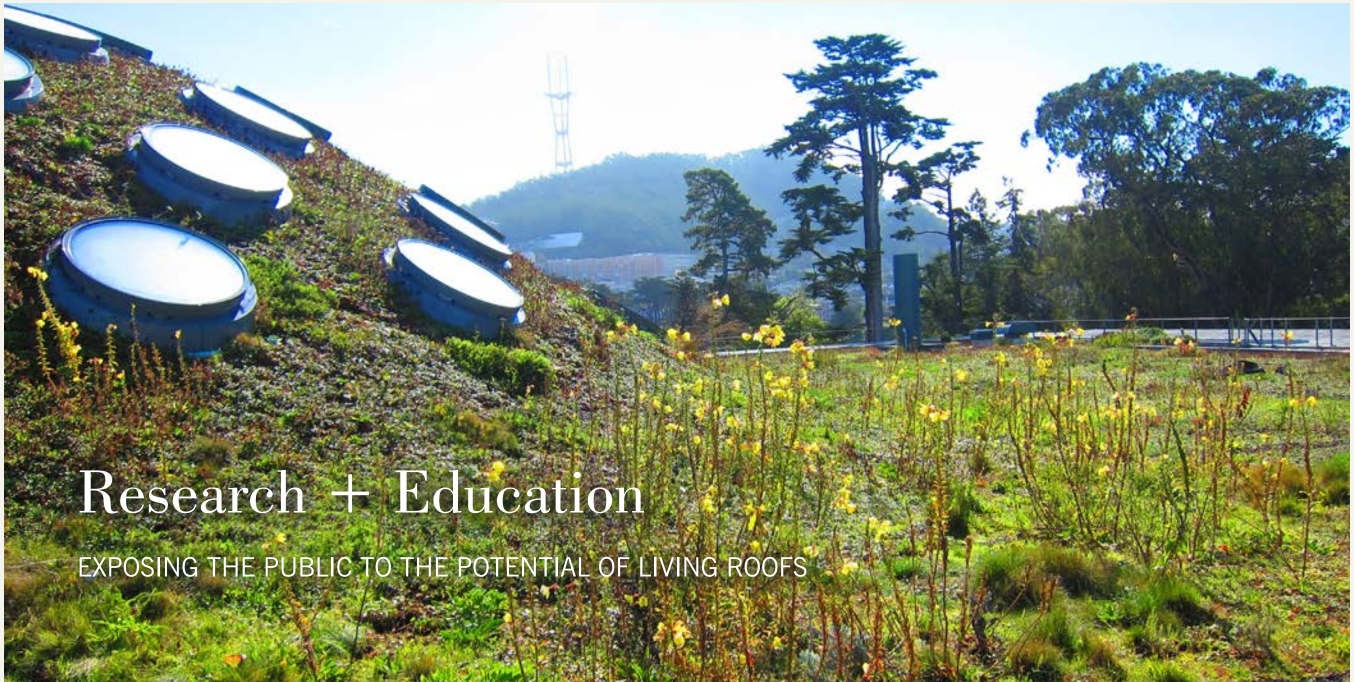


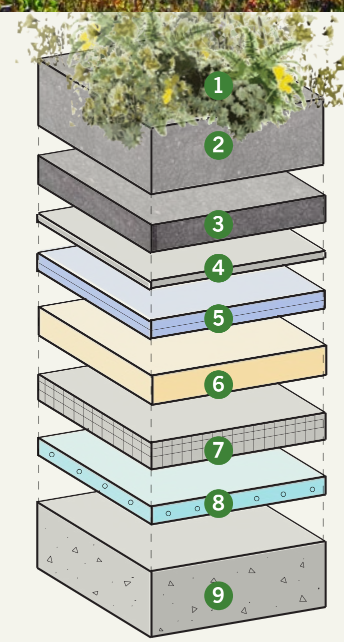
Photo by Kay Cheng, 2013.

PROJECT BACKGROUND

The California Academy of Sciences popularity provides a perfect opportunity to educate and engage the public in living roofs and local native plants.

The roof was built as a sustainability feature that could serve research and educational purposes. Some example subjects of the research taking place on the roof include: living roof plant selection, ground beetle diversity, bird habitat identification, cavity nesting native bees, ornithology, and carbon offsets. The roof's diverse structure also provides a unique research opportunity because different plants have varying reactions to the slopes of the domes.

The Academy is continuously exploring new ways to conduct scientific research and public outreach on the roof that will inform the development and sustainability of living roof technology.



ROOF SECTION

1. Native Plant Species
2. Biodegradable Trays
3. Additional Soil
4. Polypropylene Filter Sheet
5. Plastic Drainage Layer
6. Polystyrene Insulation
7. Vinyl Protection Layer
8. Thermal Plastic Waterproofing
9. Building Concrete

1 SOUTH VAN NESS

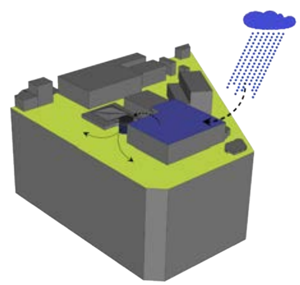
Year: **2010**

Type: **Semi-intensive**

Access: **By appointment**

Living Roof System: **Tray-based**

Designed by: **Rana Creek**



Stormwater Management

CAPTURING AND STORING AN IMPORTANT RESOURCE

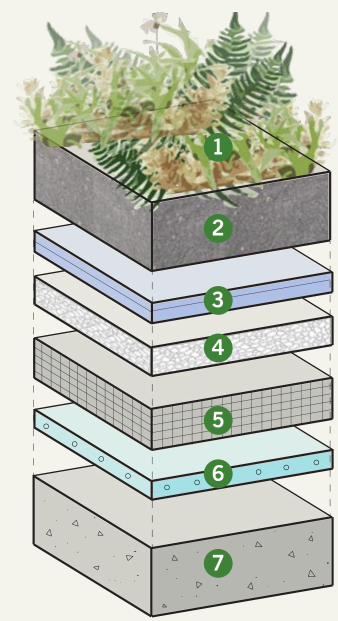
Photo by Kay Cheng, 2013

PROJECT BACKGROUND

The living roof on 1 South Van Ness absorbs storm water, reduces peak runoff, and reduces cooling loads. The roof's top story collects rainwater in a 6,500 gallon cistern and pump system. Harvested rainwater is then used for irrigating the roof, which provides a suitable habitat for butterflies, honeybees, and hummingbirds. The cistern sits on an existing mega-column that was placed on the interior of the building during a seismic upgrade.

The project team prioritized the reuse of roofing and insulation materials during construction. River rock ballasts, provided by the San Francisco Parks and Recreation Department, were reused around the edges of the living roof, while pathways were constructed out of existing concrete roof pavers.

As climate change worsens, larger storms are projected to occur more frequently, making the issue of stormwater management more pressing. Reducing stormwater runoff is one way to help solve the issue of overflowing storm drains.



ROOF SECTION

1. Native Plant Species
2. Soil & Organic Matter
3. Filter Fabric
4. Drainage Rocks
5. Foam Insulation
6. Drainage Layer/Waterproofing
7. Building Concrete

STEM KITCHEN + GARDEN

Year: **2014**

Type: **Intensive**

Access: **Semi-public**

Living Roof System: **Raised beds on concrete podium**

Designed by: **Farmscape Gardens and Engstrom Design Group**

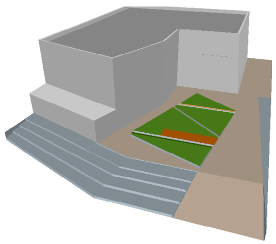
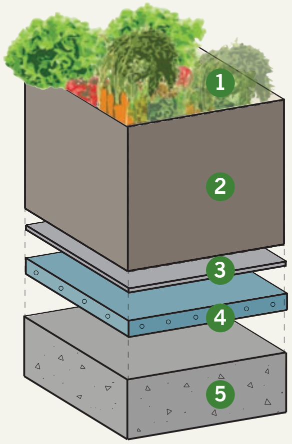


Photo by Dan Gilette, 2015.

PROJECT BACKGROUND

Every item on the menu at the STEM Kitchen + Garden in the Mission Bay neighborhood of San Francisco contains at least one ingredient grown in the on-site rooftop garden, with some dishes containing up to 80% site-grown ingredients. This gorgeous 1/4 acre garden overlooks the San Francisco bay and also includes a patio and bocce ball court. It produces 20 to 30 lbs. of produce per week, including lettuces, kale, scallions, radishes, beets, peppercress and herbs.

The 8” to 12” garden beds are filled with a soil mix and compost, and watered with drip irrigation. The restaurant has partnered with a local urban agriculture company, to maintain the garden three to four days per week. These urban farmers work closely with STEM’s chefs to select what should be grown in the garden



ROOF SECTION

1. Edible plants
2. 8-12” Growing media
3. Filter fabric
4. Drainage layer
5. Building Concrete

PART 2 | DESIGN GUIDELINES

The following design guidelines are recommendations that will help you to design and install the best possible living roof in San Francisco's unique climate. These guidelines are not currently required for permit approval. However, we recommend these guidelines be followed to the extent practicable, in order to maximize the living roof's benefits while minimizing potential issues.

FOR MORE INFORMATION:

Green Roof Design and Installation. (2013). Green Roofs for Healthy Cities.
Available from http://greeninfrastructurestore.com

Property Loss Prevention Sheet for Green Roof Systems. (2007). Factory Mutual Insurance Company.
http://www.ci.berkeley.ca.us/uploadedFiles/Planning_and_Development/Level_3_-_Energy_and_Sustainable_Development/Factory%20Mutual%20Green%20Roof%20System.pdf

Guidelines for the Planning, Installation and Maintenance of Green Roofing. (2008). The German Landscape Research, Development and Construction Society (FLL).
Available from *http://www.fll.de/shop/english-publications.html*

Design Guidelines and Maintenance Manual for Green Roofs in the Semi-arid and Arid West. (2010). Tolderlund, L.
http://www2.epa.gov/sites/production/files/documents/GreenRoofsSemiAridAridWest.pdf

Structural

1. **Hire a structural engineer to assess the roof's structural capacity and seismic resistance**
2. **Only install living roofs over structures capable of bearing their weight**

Waterproofing

3. **Use a proven, durable material that is resistant to punctures, and does not emit harmful vapors**
4. **Use a root barrier or tested root resistant waterproofing layer**
5. **Conduct a leak test prior to installing additional roof layers and/or install a permanent leak detection system**

Drainage + Water Retention

6. **Maximize water retention, within the building's structural loading parameters**
7. **Ensure proper drainage from all roof surfaces**
8. **Install secondary roof drains, and keep all drains clear of debris**

See page 45 for photo credits.

Growing Media

9. Use lightweight growing media materials, sourced locally when possible
10. Specify growing media depth of at least 4 inches
11. Test the growing media periodically to assess nutrient levels

Irrigation

12. Minimize water use through high efficiency irrigation
13. Assess the feasibility of non-potable water sources
14. Match the irrigation system to the plant types

Plants

15. Utilize a high percentage of low-water use and low-maintenance species
16. Specify roof-appropriate native species
17. Provide high species diversity

Habitat

18. Include multiple habitat "niches"
19. Plant native species with high habitat value
20. Provide essential habitat features for birds and insects, such as shelter and water sources

Rooftop Agriculture

21. Avoid planting crops with deep taproots
22. Use slow-release organic fertilizers and biological pest control menthods

Construction

23. Coordinate trades to ensure efficient construction
24. Prioritize safety by following all applicable fall protection requirements
25. Avoid soil media compaction and rooftop stockpiling during construction activities

Maintenance

26. Design for the desired level of maintenance
27. Provide a detailed maintenance manual
28. Plan for ongoing maintenance

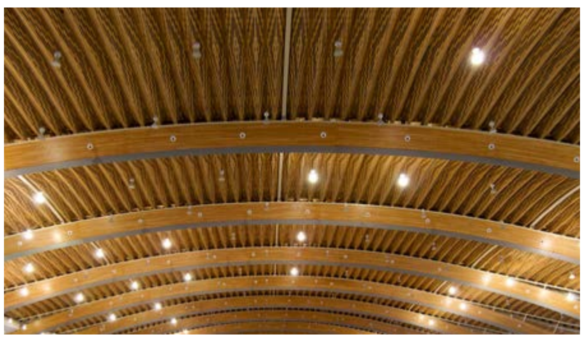
See page 45 for photo credits.

6. Structural

RECOMMENDATIONS

1. Have a structural engineer assess the roof's excess structural capacity and seismic resistance

2. Only Install living roofs over structures capable of bearing their weight



FOR MORE INFORMATION:
ASTM Technical Guide E2397 - Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems

Tapping the Potential of Urban Rooftops. (2007). Bay Localize.
http://www.baylocalize.org/files/Tapping_the_Potential_Final.pdf

Living roofs can weigh anywhere from 15 pounds to over 200 pounds per square foot (psf). Therefore, the structural capacity of the roof, and the additional weight of the living roof system, is one of the most important considerations in living roof design. The roof structure must be able to accommodate this additional load, as well as the expected weight of water and people. For existing buildings, the roof should be assessed by a structural engineer before continuing with design. The type of living roof that can be built is often dependent on, and limited by, the load bearing capacity of the roof. Upgrading a roof to hold more weight or adding additional capacity to the design of a new roof can be expensive, and should be accounted for in the total project cost. The weight of a living roof depends primarily on the depth of it's soil media, the soil media's composition, and the water retention capacity.

Determining Additional Loading Capacity

The additional loading capacity of existing buildings depends on the building type, construction materials, the expected use of the rooftop, and the construction era. Residential buildings will typically have greater additional loading capacity than warehouses and big-box type buildings, for example. In new construction, the roof can be designed to accommodate the additional load imposed by the living roof.

Selecting an Engineer

A licensed structural engineer should determine the loads associated with the existing roof and the proposed living roof, and be familiar with living roofs and their loading requirements. In addition, the engineer should be familiar with California Building Code requirements for living roofs and San Francisco seismic requirements.

California Building Code Calculations for Living Roof Loading

According to the California Building Code, the total weight that a roof must accommodate is classified into two types of loads: dead load and live load.

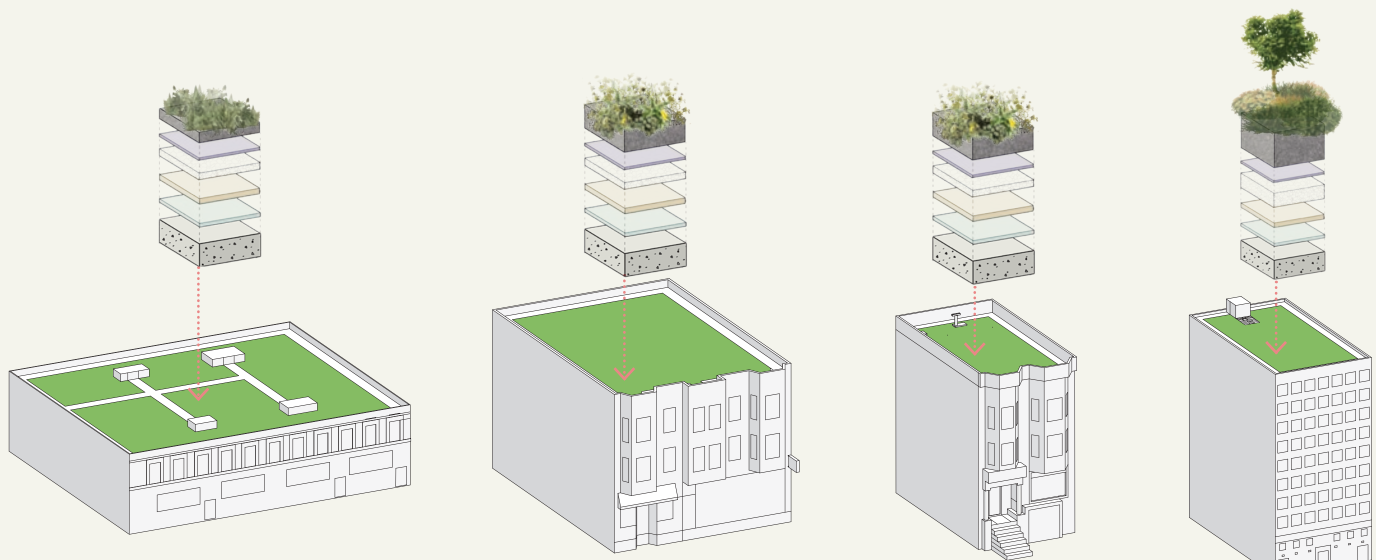
Dead Load is the intrinsic weight of the structure itself. This includes all materials and components that contribute to roof construction, including all living roof layers, growing media, and vegetation, under fully water saturated conditions.

Live Load is the additional weight that must be supported by the structure during its use and occupancy. Occupiable roof gardens and assembly areas should be designed for a live load of 100 psf, while unoccupied landscaped areas shall have a uniform design live load of 20 psf. (Per California Building Code, Section 1607).

Photo: 'Richmond Olympic Oval intern View', by Thelastminute (Duncan Rawlinson), CC BY 2.0, via Wikimedia Commons (cropped from original).

Living Roofs + Structural Capacity

	Warehouse	Mixed residential and commercial	Single family residential	Office
ADDITIONAL LOADING CAPACITY (TYPICAL)[1]	Low (5-10 psf)	Medium (15-20 psf)	Medium (20 psf)	High (60-80 psf)
APPROPRIATE LIVING ROOF SYSTEM	Extensive	Semi-intensive	Semi-intensive	Intensive
SYSTEM WEIGHT (FULLY SATURATED)[2]	10-35 lbs./ft^2	35-50 lbs./ft^2	35-50 lbs./ft^2	50-300 lbs./ft^2
BUILDING TYPE	Warehouse (Requires structural reinforcement)	Mixed residential and commercial (May require structural reinforcement)	Single family residential (May require structural reinforcement)	Office (New Construction)



*1. Actual additional loading capacity will vary, consult an engineer to assess the building before specifying a living roof type. Source: Tapping the Potential of Urban Rooftops. (2007). Bay Localize.
Retrieved from http://www.baylocalize.org/files/Tapping_the_Potential_Final.pdf
2. Source: Green Roofs for Healthy Cities. (2013). Green Roof Design and Installation Design Manual, pg 18.

7. Waterproofing

RECOMMENDATIONS

17 Use a proven, durable waterproofing material that is resistant to punctures, and does not emit harmful vapors

18 Use a root barrier or tested root resistant waterproofing layer

19 Always conduct a leak test prior to installing additional roof layers and or install a permanent leak detection system

'Construction', photo courtesy Awie Smit, Habitat Gardens.

FOR MORE INFORMATION:
Green Roof Waterproofing and Drainage Manual. Green Roofs for Healthy Cities.
Available from http://greeninfrastructurestore.com/Green-Roof-Waterproofing-and-Drainage.html

A roof's primary function is to keep the people and things inside a building dry and protected from the outside elements. Living roofs must still perform this function in addition to providing stormwater retention and plant habitat. A number of different waterproofing materials can be used with living roofs, however, extra care is sometimes needed in order to protect these waterproof membranes from damage by plant root growth.

Root Barriers

Plants' roots are remarkable in their ability to push through seemingly solid layers in their quest for water and nutrients. Punctures to this critical layer will cause roof leaks, requiring costly repairs.

One solution to this is the inclusion of a root barrier layer, either made from high density polyethylene (HDPE) or polyvinyl chloride (PVC). Some roof waterproofing materials, such as single-ply thermoset and thermoplastic membranes, may not need an additional root barrier. However, for built-up-roofs (BUR) and modified bitumen (MB) membranes, a root barrier is essential, as the organic material in this layer is susceptible to root penetration and microbial degradation. Not all materials are compatible with one another - namely bitumen and PVC, and may require an additional protection course between membrane and root barrier.

Insulation

While not considered one of the critical components of living roof systems, an insulation layer helps mitigate the heat loss or gain that the building might experience from water that is stored within the living roof system. In winter, this water could draw heat away from the building, with the reverse effect in the summer. For living roof retrofits, insulation is often included in the project scope to help improve the overall building insulation. Conventionally, roofs were constructed with insulation under the waterproofing membrane. Protected-membrane roofing (PMR) systems (with the insulation above the waterproofing layer) may extend the life of the membrane by providing further protection for the waterproofing membrane during construction, installation, and maintenance activities. Extruded polystyrene insulation is often used as insulation because it does not easily absorb water.

Leak Detection

Leak detection systems can be included beneath the waterproofing layer. These systems utilize electric currents to help pinpoint the location of the leak, thus saving the time and expense of repairing large sections of roof. Weather using a leak detection system or not, it is important to conduct a leak test to ensure that the waterproofing is watertight.

8. Water Retention and Drainage

RECOMMENDATIONS

20 Maximize water retention, within the building's structural loading parameters

21 Ensure proper drainage from all roof surfaces

22 Install secondary roof drains, and keep all drains clear of debris

FOR MORE INFORMATION:
ASTM Technical Guides
E2398 - Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Vegetative (Green) Roof Systems

E2788 - Specification for Use of Expanded Shale, Clay and Slate (ESCS) as a Mineral Component in the Growing Media and the Drainage Layer for Vegetative (Green) Roof Systems

San Francisco Stormwater Design Guidelines
http://www.sfwater.org/Modules/ShowDocument.aspx?documentID=2779

Optimizing a living roof's drainage system is both challenging and fundamental to its overall performance as a medium for plant growth and a stormwater control device. Living roofs should be designed to reduce the total volume and intensity of stormwater entering the sewer system, while also attempting to make this water available to plants. However, growing media should be well-drained for healthy plant growth, and the roof's structural loading limitations reinforce the need for water to drain quickly through the living roof layers. Ultimately, a balance must be achieved between drainage and water retention.

Drainage Types

There are several options for drainage layers, including mineral aggregates and geocomposites. Mineral aggregates contain lightweight, inorganic particles of a larger size (1/8 - 1/2") than what is found in the growing media. Geocomposites are engineered plates and mats that have built-in water retention capacity. These geocomposites have perforations or "cups" which are installed facing upwards, so that they can fill with water after a storm event. The roots of the plants above are then able to penetrate the filter fabric layer and access the water in these cups, decreasing the need for irrigation.

Roof Drainage

Although living roofs are capable of retaining significant amounts of water, they will still generate runoff during intense storms when the soil and water retention system reaches saturation. Rainwater will land on the plants, percolate through the soil media into the drainage layer, collect in the conveyance system, flow to the roof drains, and eventually exit through the downspouts into the City's sewer system.


'A roof drain', by Kerby Olsen, 2014.

Most flat roofs are required to have multiple drains so that the roof can shed water even if the primary drain is clogged. A living roof system makes it even more important to have and maintain multiple drainage points. If a primary drain pipe became clogged, additional rainfall and loading on the roof could present a hazardous situation and potentially lead to roof collapse.

Drains are typically surrounded by grates and a 3 ft. planting-free area, to protect them from debris and other items that could cause clogging. This ensures that the drain is protected from all of the living roof layers and falling debris (twigs, leaves, etc.), while maintaining an easy access point for maintenance personnel to perform inspections.

9. Growing Media

RECOMMENDATIONS

11 Use lightweight growing media materials, sourced locally when possible

12 Growing media depth should be at least 4 inches

13 Test the growing media periodically to assess nutrient levels

FOR MORE INFORMATION:

ASTM Technical Guide E2788 - Specification for Use of Expanded Shale, Clay and Slate (ESCS) as a Mineral Component in the Growing Media and the Drainage Layer for Vegetative (Green) Roof Systems

Green Roof Plants and Growing Media Manual. Green Roofs for Healthy Cities.
Available from http://greeninfrastructurestore.com/Green-Roof-Waterproofing-and-Drainage.html

Soil plays a critical role for both ground-level plants and living roofs, providing a structure to which roots can attach, retaining moisture after rainfall, providing minerals and nutrients, and allowing for gas exchange. On a living roof, these functions are just as essential as on the ground, but must be otherwise engineered to address the limitations associated with rooftop placement. For these reasons, this living roof layer is generally referred to as the "growing media" and should not be simply equated with the topsoil that one would find at ground level.

The actual composition and dimensions of the growing media layer will vary between projects, depending on the structural loads the building can support, the type of living roof that is being designed, and the plants that are included. Many living roof manufacturers now offer their own engineered growing media mix, often specifically tailored to the plants that make up their vegetation layer. Soil professionals may also develop a custom mix based on project-specific needs. In all cases, growing media should not contain materials that have the potential to release or leach harmful substances into the environment or the living roof vegetation.

Growing Media Composition

Despite the variety and combinations of growing media that exist, the basic building blocks are the same - organic material, minerals, and the space between then (known as pore space).

'Soil media', by Kerby Olsen, 2015.

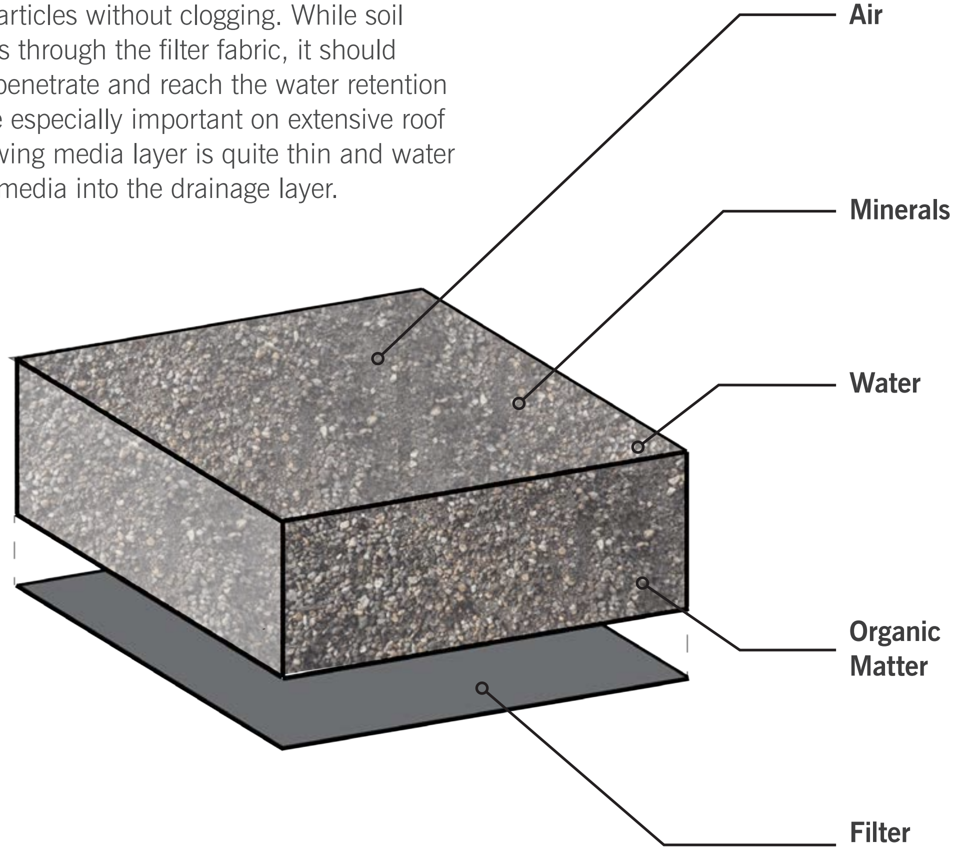
Organic material accumulates in soil over time as plants and animals die, decompose, and recycle their nutrients. On the rooftop, as organic matter is depleted, growing media may become compacted and brittle, inhibiting both water storage and root growth. Rooftop organic material can come from loamy topsoil, compost, sawdust, leaves, and agricultural wastes.

Minerals are the dominant element of natural soils and growing media. They are characterized by their particle size and density into three broad classes, in order of decreasing size: sands, silts, and clays. Growing media can be composed of naturally occurring materials like volcanic pumice, perlite, and scoria, or synthetically produced materials such as expanded clay, shale, and slate pellets.

Filter Fabrics

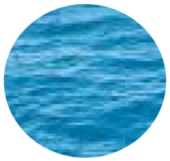
Filter fabrics are typically made from a geosynthetic fabric or geotextile, often either polyethylene or polypropylene. The fabric can either be woven or not. However, for growing media with high clay content (>15%), a woven layer will be capable of filtering out smaller particles without clogging. While soil particles should not pass through the filter fabric, it should allow for some roots to penetrate and reach the water retention layer below. This can be especially important on extensive roof systems, where the growing media layer is quite thin and water drains quickly from the media into the drainage layer.

Components of the Growing Media Layer



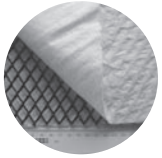
Air exists in the space between minerals and organic material. This air space is then available to be occupied by moisture, plant roots, or living organisms.

The variation and distribution of particle sizes will directly impact water retention properties.



Living roof soils are designed to retain moisture, but also to allow that moisture to slowly drain off of the roof.

The initial soil media mix should have higher organic content to account for loss over time. Additions of organic material may be needed as part of periodic maintenance.



Filter fabric provides a barrier that allows water to pass to the drainage layer and prevents fine particles from passing through.

Photos (top to bottom): 1. Air, 2. 'Scoria', by Chmee2, CC BY-SA 3.0, 3. 'Blue water', by Downtowngal, CC BY-SA 3.0 (cropped from original), 4. 'Compost-dirt', By normanack [CC BY 2.0 (http://creativecommons.org/licenses/by/2.0)], via Wikimedia Commons, (cropped from original), 5."Geocomposite drain2", by Werner W Müller and Fokke, CC BY 3.0 (cropped from original).

10. Irrigation

RECOMMENDATIONS

14 Minimize water demand through design

15 Assess the feasibility of non-potable water sources

16 Specify high-efficiency irrigation systems matched to plant types

'Micro-spray irrigation', photo courtesy Hunter Industries.

FOR MORE INFORMATION:

San Francisco Water Efficient Landscape
http://sfwater.org/index.aspx?page=689

Gardens and Landscapes
www.sfwater.org/landscape

A Guide to Drip Irrigation. The Urban Farmer Store.
http://www.urbanfarmerstore.com/pdflibrary/drip-irrigation/

In San Francisco's warm-summer Mediterranean climate[1], irrigation is an essential consideration for almost all living roofs. San Francisco's dry season lasts from approximately late May to mid-September, during which little to no precipitation may occur. In addition, the typically free –draining and shallow soil profile of a living roof means that very little water is stored in the soil, when compared to healthy native soils. Although living roof plants should be selected for their drought tolerance, few plants can survive four months in hot and exposed conditions without water. Seasonal dormancy is normal and expected for many native plants in California, but a living roof with dead plants would lose much of its functionality and create a fire hazard. Therefore, some irrigation will be necessary in order to keep living roof plants and soil ecology healthy and biologically active. However, water use can be minimized through the selection of plants, irrigation systems, soil media and water retention systems.

There are several different types of irrigation that may be appropriate for living roofs, including drip irrigation, efficient spray irrigation and subsurface capillary mats. The irrigation system should be tailored to the site's environmental conditions, plant selection and soil media, in order to provide the appropriate amount of water at the correct location for maximum plant uptake.

The California Fire Code (2013) requires that living roofs not become a fire hazard via through the accumulation of dry plant material. San Francisco's Water Efficient Irrigation Ordinance applies to all new or modified landscaped areas, including living roofs. This ordinance influences the selection of plants and irrigation systems, and establishes a water budget for the project. Please refer to the SF PUC's Water Efficient Landscape website for compliance information.

Irrigation controllers and flow sensors

Modern irrigation systems include digital controllers that open and close electronic "solenoid" valves, releasing water to specific areas on a predetermined schedule, or in response to soil and atmospheric conditions. These systems also allow for different parts of the roof or landscape to receive different amounts and durations of water, as necessary per each plant's watering requirements. These controllers can be paired with a small weather station, which will reduce watering in response to rain events, or increase watering in response to extreme heat. Digital controllers can also be programmed to reduce watering after the initial establishment period of approximately 3 to 6 months. Planting in the fall or winter can take advantage of natural rainfall during establishment. Irrigation controllers can also be paired with flow sensors to minimize water waste. Flow sensors can help to reduce the risk of water loss

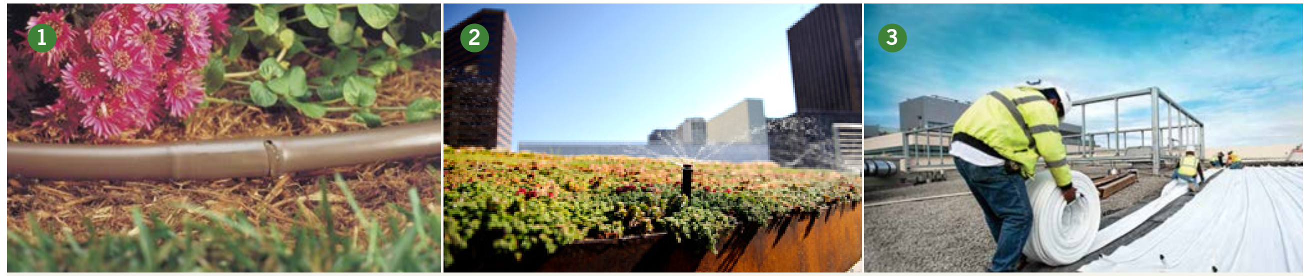
1. According to the Koppen climate classification system. Source: Climate of California. Retrieved from https: en.wikipedia.org/wiki/Climate_of_California

from breaks in the irrigation system by monitoring and automatically responding to the actual flow conditions. For example, if a leak were to develop in an irrigation line, the flow sensor could send a signal to the irrigation controller, shutting down water flow to the broken line.

Water retention

The amount of irrigation required on a living roof is highly dependent on the roof's water retention capability. Water can be retained on a roof by the soil, plants, and/or water retention layer. The soil media mix will impact water retention, as soils with a higher organic material content will hold more water. Soil depth also influences retention, with thicker soils retaining more water. Soils should be thick enough to retain sufficient water to minimize irrigation, with a recommended minimum depth of 4".

A water retention layer may help to reduce irrigation demand, while simultaneously increasing stormwater retention. The small cups or absorptive materials that compose the retention layer hold water that is accessible to plant roots, but free of soil, potentially extending the amount of time between waterings.



Irrigation Types

1. DRIP IRRIGATION

Drip irrigation consists of plastic tubing with regularly spaced, small holes or "orifices" that emit water at a slow, predetermined rate. This tubing can be buried several inches into the soil, laid on top of the soil, or laid beneath mulch, however, the tubing should be kept out of direct sun exposure. Drip tubing is designed with various emitter spacing and water emission rates, which can be matched to the expected soil conditions. Irrigation tubing should be spaced closer together in sandy soils than in clayey soils. Living roof soils tend to behave more like sandy soils, with free draining characteristics. Therefore, lines of drip irrigation tubing may need to be spaced close together (6" to 1') in order to access all plants roots.

2. SPRAY IRRIGATION

Since the advent of drip irrigation, spray irrigation has come to be seen as less efficient. However, recent advances have led to smaller, more distributed spray irrigation systems that emit larger droplets of water, spray more accurately and lose far less water to the atmosphere than previous versions. The free draining character of living roof soil may mean that spray irrigation can spread water more evenly across the roof than drip systems. However, the prevailing wind conditions should be analyzed when designing a spray irrigation system. Rooftops are often much windier than the ground surface, and spray irrigation is subject to being blown off-course by strong or frequent winds. Generally, the larger the water droplets coming from the spray head, the more resistant they are to wind forces. Other design considerations for spray irrigation include making sure that the spray emitter is higher than the fully grown plant height and ensuring that the spray avoids walkways and rooftop equipment.

3. CAPILLARY MAT IRRIGATION

Capillary mat irrigation systems incorporate both sub-surface water distribution lines and a fleece or felt material to spread that water laterally into the root zone. Capillary action then pulls the water out of the mat and into the soil. These systems are designed to be highly water efficient.

Photo (left to right): 1. 'Drip tubing', photo courtesy Hunter Industries, 2. 'Micro-spray irrigation', photo courtesy Hunter Industries, 3. 'Eco-mat installation', photo courtesy Hunter Industries.

Alternate Water Sources

Potable water use on living roofs can be offset through alternate water sources such as harvested rainwater, greywater, recycled water, and /or cooling tower blow-down. Each of these water sources are typically sent to the sewer or storm drain system. Utilizing these sources for irrigation can reduce potable water use, while maintaining healthy roof plants. The use of alternate water source irrigation systems may require a permit from the Department of Public Health, and a plumbing permit from the Department of Building Inspection. See the SF PUC's On-site Non-potable Water Use guide and Non-potable water use program website for more information.

FOR MORE INFORMATION:

San Francisco Non-potable Water Program
www.sfwater.org/np

San Francisco's Non-potable Water Program Guidebook
http://sfwater.org/modules/showdocument.aspx?documentid=4962

California Greywater Regulations
California Plumbing Code, Chapter 16

San Francisco Greywater Design Manual (2012)
http://sfwater.org/modules/showdocument.aspx?documentid=55

Alternate Water Sources

	1. RAINWATER	2. GREYWATER	3. RECYCLED WATER	4. BLOW-DOWN WATER
	Rainwater harvesting involves the capture, filtration, and storage of rainwater that falls on the roofs and other above grade surfaces of a site. Rainwater is typically very clean, but may pick up bacteria and particulates from roof surfaces.	Greywater is wastewater from showers, bathroom sinks, and laundry machines. Greywater contains contaminants that may require filtration or treatment, depending on the end use of the water.	Recycled water is wastewater that has been purified so it can be used again for new purposes. Depending on the classification of the recycled water, it can generally be used for all landscape irrigation, including on living roofs.	Blow-down water is drained from building cooling systems to avoid mineral build-up. This water can sometimes be harvested for re-use, but may need to be diluted with other water sources due to high mineral content.
ADVANTAGES	• Also serves as stormwater retention • Minimal filtering and treatment for non-potable applications • Ideal pH level	• Predictable, based on building occupancy • May contain plant nutrients • Generally lower storage capacity required	• Reliable and consistent • Does not require additional filtration by the end user • Greater levels of NPK plant nutrients	• Little or no storage required • Greatest availability in summer when both irriga-tion and cooling demand are highest
DISADVANTAGES	• Long term storage may be required • May require large storage system • Rainfall is greatest when irrigation demand is lowest • Yearly rainfall varies	• Requires more involved filtration • Must be used within 24 hours • May require the use of biodegradable soaps and detergents.	• Not available in all areas of the City • May require additional plumbing • pH and salt levels may be non-optimal	• May contian high mineral content, pathogens and/or chemicals • May cause mineral build-up in soil

Photos (left to right): 1. 'Refraction of Golden Gate Bridge in rain droplets', by Brocken Inaglory (Own work) CC BY-SA 3.0, (cropped from original) 2. 'Showerhead', by Geoffrey Fairchild, CC BY 2.0 (cropped from original), 3. 'Purple pipe', by John Loo, CC BY 2.0 (cropped from original), 4. 'Rooftop mechanical equipment', by Patrick Race, 2014.

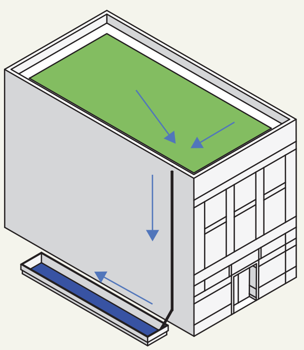
Living Roofs and Rainwater Harvesting

Rainwater harvesting is becoming a common way for buildings in San Francisco to save water and comply with stormwater regulations. Living roofs may be used in conjunction with rainwater harvesting systems, but additional considerations may apply.

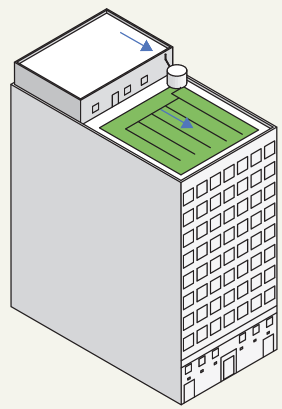
It is generally best to harvest rainwater from portions of the roof that are impervious and not connected to the same drainage system as the living roof portion. This rainwater may then be stored, filtered, and used for non-potable applications, including irrigation of the living roof. Rainwater runoff from a living roof can also be directed into a rainwater cistern for storage and re-use, however additional filtration may be required. Living roof runoff may contain small amounts of nutrients, dissolved organic matter, tannins and/or fine sediment. These materials are difficult to filter and may cause bacterial growth, making the stormwater runoff inappropriate for long-term storage without prior filtration. Be sure to consult with a water treatment system design professional when determining how to best harvest and treat rainwater for reuse at your site.

Living Roofs + Rainwater Harvesting

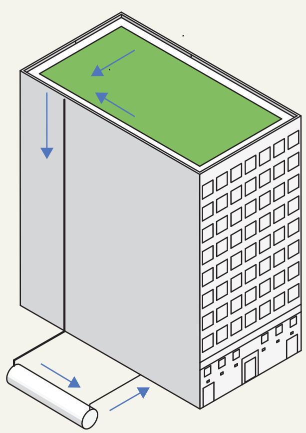
POTENTIAL USES



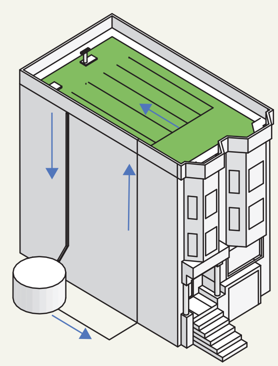
Stormwater runoff from living roof directed to in-ground infiltration feature



Stormwater runoff from impervious roof area harvested and used to irrigate living roof



Stormwater runoff from living roof sent to on-site water treatment system



Stormwater runoff from living roof area directed to rainwater harvesting system, additional filtration may be needed

11. Plants

RECOMMENDATIONS

3 Utilize a high percentage of low-water use and low maintenance species

4 Specify roof-appropriate native species

5 Provide high species diversity

California Poppies at UCSF by Kerby Olsen, 2015.

FOR MORE INFORMATION:

San Francisco Green Connections
http://greenconnections.sfplanning.org

San Francisco Plant Finder
http://sfplantfinder.org/about.html

Green Roof Plants: A Resource and Planting Guide. (2006). Snodgrass, E.C., and Snodgrass, L.L.

ASTM E2400 Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems
http://www.astm.org/Standards/E2400.htm

The plants that flourish in the harsh conditions on top of a roof tend to be adapted to environments with thin, fast draining soils and full sun exposure, such as rocky outcroppings, deserts or sand dunes. These plants are sun loving, low-nutrient tolerant, heat tolerant, and low maintenance, making them ideal for surviving on a living roof. Living roof plants should also have shallow, fibrous roots that will allow them to resist wind, while holding the soil media. The City's many micro-climates create unique conditions, such as dense fog, sea spray, and heavy wind, which should be considered when selecting plants. Living roof plants should not be invasive, and should ideally be perennials or self-seeding annuals. The recommended plant list on the following page was compiled from observation of plants that have proven successful on multiple rooftops in San Francisco.

Biodiversity

A biodiverse plant selection gives the living roof a better chance of overall success, even if a few species are not able to survive. In addition, a diverse species composition may allow for beneficial relationships, such as complementary flowering periods. The San Francisco Green Connections Plan is a great resource for learning about San Francisco's unique ecosystem, plants and animal communities, and includes a plantfinder, design toolkit and ecology guides. The online San Francisco Plantfinder tool includes a searchable database of plants that are appropriate for any rooftop in San Francisco, based on micro-climatic conditions.

Plant selection

The living roof environment poses a unique set of challenges for designers as well as plants. While native plants are desirable for their habitat benefits, some non-native species are extremely well suited to the living roof environment. For example, the *Sedum* family has minimal water needs, fibrous lateral roots, and tolerance of full sun, heat and cold (San Francisco even has a native *Sedum*, the stonecrop). Rooftop plant selection can include a mixture of both natives and non-natives, with *Sedum* species providing ground coverage while more upright native flowers, grasses and shrubs provide vertical accents and colors. The greatest challenge for the living roof designer is to choose the plants that best fit the goals of the project.

Planting

Living roofs can be planted as plugs, cuttings, or vegetated mats, and can also be direct-seeded.

Plugs are plants that have been grown in a nursery until they are 3" to 6" tall. These plants are grown in vertical containers that are long and thin, and come equipped with a deep root structure that can quickly access subsurface moisture. However, plugs are typically more expensive than seeds or cuttings due to the labor involved with growing them.

Cuttings are fragments of *Sedum* plants that have fallen off of a main plant. These cuttings can completely regrow into a full plant, given the right conditions. Cuttings will flower in the second year after planting.

Direct seeding living roofs is also possible, through hand spreading or hydro-seeding. Hydro-seeding involves the spraying of a mixture of seeds and fiber mulch or fertilizer. These methods will not provide rapid coverage, as seeds will take time to establish themselves.

Vegetated mats or trays are grown in an off-site nursery and delivered complete with soil media, and possibly a tray. A vegetated mat can be cut and placed directly on the roof or placed into a tray system. These off-site planting techniques have the advantage of immediate full or nearly full coverage upon installation. However, they may be more costly than on-site planting due to the additional labor involved. They can also be readily replaced, in whole or in part, whether to address mortality or otherwise modify the living roof for aesthetic purposes.

Recommended Plant List

PROVEN ON NUMEROUS ROOFTOPS IN SAN FRANCISCO

Achillea millefolium
Common yarrow

Arctostaphylos uva-ursi
California Bearberry

Armeria maritima
Sea thrift

Eschozia californica
California poppy

Epilobium canum
California fuschia

Festuca californica
California fescue

Fragaria chiloensis
Beach strawberry

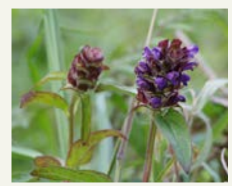
Juncus patens
Spreading rush

Lupinus bicolor
Miniature lupine

Mimulus aurantiacus
Sticky monkey flower

Muhlenbergia rigens
Deergrass

Nemophila menziesii
Baby blue-eyes



Prunella vulgaris
Self-heal

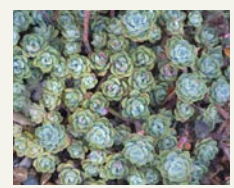
Sisyrinchium bellum
Blue-eyed grass

Sedum acre
Goldmoss stonecrop

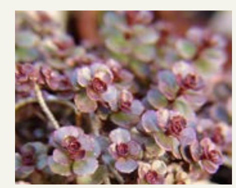
Sedum album
White stonecrop

Sedum kamtschaticum
Yellow Stonecrop

Sedum oreganum
Oregon stonecrop



Sedum spathulifolium
Cape blanco stonecrop



Sedum spurium
Dragon's blood sedum

See page 45 for photo credits.

12. Habitat

RECOMMENDATIONS

6 Design multiple habitat “niches”

7 Plant native species with high habitat value

8 Provide essential habitat features for birds and insects, such as shelter and water sources


A box of sticks and logs provides habitat for cavity-nesting native bees on the California Academy of Sciences living roof. Photo by Kendra Hauser, 2015.

FOR MORE INFORMATION:

Natural San Francisco
http://www.sfenvironment.org/biodiversity

San Francisco Urban Forest Plan
http://www.sf-planning.org/ftp/files/plans-and-programs/planning-for-the-city/urban-forest-plan/Urban_Forest_Plan_Final-092314WEB.pdf

California Academy of Sciences Living Roof Plantlist
https://www.inaturalist.org/guides/1556

San Francisco is still home to over 450 native plants, hundreds of species of birds, as well as many native mammals, reptiles and amphibians, in addition to countless introduced species. This diversity of plants and animals contributes to local ecological resilience, while providing ecosystem services such as pollination and air filtration. For many species, the urban environment can be a tough place to live. Very little remains of the dunes, scrublands and grasslands that once dominated the landscape. Living roofs hold the potential to recreate some of that lost habitat in the air above us, allowing both humans and local species to coexist in the same space. Living roofs even have the potential to act as a “bridge” between fragmented native habitats, similar to restoration efforts underway to unite small pockets of extant habitat for the Green hairstreak butterfly[1].

Evidence from around the world

Living roofs across the world have successfully created habitat for many species, usually birds and insects. A study in New York City found that 26 species of birds visit living roofs, including flycatchers, magnolia warblers and peregrine falcons[2]. One survey of living roofs in Basel, Switzerland, found up to 79 beetle and 40 spider species, with 13 of the beetle and 7 of the spider species considered endangered[3].

Designing habitat

Through extensive research and careful planning, some of San Francisco’s living roofs have become excellent examples of habitat recreation. Future living roof designers can learn from these examples, while designing roofs that are appropriate to the unique micro-scale conditions of each building site. The California Academy of Sciences and the Heron’s Head EcoCenter are two examples of successful habitat creation.

Each element of a living roof can provide habitat in a variety of ways. The plants can provide forage for bees, insects and humming birds. Soil media can be a refuge for beetles, spiders and even worms. Features such as ponds, logs, and dirt mounds can be used to target specific habitat needs that would otherwise not be present on a standard roof or even a typical living roof. When taken together, these design elements might provide enough habitat for an insect to live out its entire life cycle, or simply provide a temporary refuge for migrating species. Greater ecosystem value can be created by designing multiple “niche” habitats within the roof. Within each niche, varied soil depths and light exposure might support a range of plant types that provide an urban refuge for a diversity of insects and birds.

Sources:
1. Nature in the City. (2015). Green hairstreak corridor. Retrieved from http://natureinthecity.org/green-hairstreak-corridor/
2. Nuwer, R. (2014). Wildlife Oases in New York’s Concrete Jungle. Retrieved from https://www.nwf.org/News-and-Magazines/National-Wildlife/Gardening/Archives/2014/New-York-Green-Roofs.aspx
3. Brenneisen, S. (2006). Spaces for urban wildlife: Designing green roofs as habitat in Switzerland. Retrieved from http://www.urbanhabitats.org/v04n01/wildlife_full.html

Interview with Kendra Hauser
California Academy of Sciences

How does your living roof provide habitat?

The California Academy of Sciences' living roof is 2.5 acres and composed of over 90 species of California native plants. We take an active role in selecting local native plants, introduce plant species that are important nectar, pollen, and seed sources for wildlife, and develop our plantings to incorporate plant species that will bloom at varying times of the year to maximize food sources. Emphasis is not only placed on providing food sources for local species, but also ensuring that wildlife has shelter for nesting and hiding from predators. To achieve this we select plants of varying heights, grass species, and incorporate rocks and branches on the roof. To encourage California native bees to nest on the roof, we created earth mounds and a bee house composed of logs.

What types of species regularly visit the living roof?

We have had a variety of birds visit the roof, including the Lesser goldfinch, black phoebe, dark-eyed junco, and Anna's hummingbird. Two reoccurring bird visitors are the killdeer and red-tailed hawk. Red-tailed hawks have been nesting in a Monterey Cypress on our grounds for many years. Within two years of the roof being installed, the hawks began using the roof as a space for their fledglings to practice flight. Nearly every day in the summer we will see the hawks sunning on the domes or feeding on the roof! A variety of bees, butterflies, and moths also visit the roof. We are always excited and surprised to see new ground dwelling animals as inhabitants in our growing media and currently have spiders, beetles, grasshoppers, pill bugs, and earth worms on the roof!

Welcoming Native Species

SPECIES	RECOMMENDED FOOD AND HABITAT PLANTS			OTHER HABITAT ELEMENTS
 **Hummingbirds** *Anna's hummingbird*	 *California fuschia*	 *Hummingbird sage*	 *California Bearberry*	 **Tree branches for resting**
 **Bees** *California bumble bee*	 *Miniature lupine*	 *Coast buckwheat*	 *Yarrow*	 **Earth mounds for burrowing**
 **Butterflies** *Green hairstreak*	 *Deerweed*	 *Sea thrift*	 *Seaside daisy*	 **Pond for water source**

See page 45 for photo credits.

13. Rooftop Agriculture

RECOMMENDATIONS

9 Avoid planting crops with deep taproots

10 Use slow-release fertilizers and biological pest control menthods

A dish at STEM Kitchen + Garden features produce grown on a living roof. Photo by Anne Brask, 2015.

FOR MORE INFORMATION:

Starting a Garden or Urban Farm in San Francisco
http://sfrecpark.org/wp-content/uploads/HowToStartAGarden_Final-USE-THIS-ONE.compressed2.pdf

San Francisco Urban Agriculture Program
http://sfrecpark.org/park-improvements/urban-agriculture-program-citywide/

San Francisco Urban Agriculture Alliance
http://www.sfuaa.org/

San Francisco Beekeepers Association
http://www.sfbee.org

Living roofs provide an opportunity to bring agriculture back into the City. Rooftop urban agriculture provides access to fresh fruits and vegetables, lowers the greenhouse gas emissions associated with food shipments, and can educate consumers about agriculture. Design considerations for living roofs incorporating edible crops are similar to those for other living roofs, but with a few exceptions and additions.

Edible plants generally require more maintenance than landscape plants, therefore footpaths should be provided throughout the roof. Storage areas should be provided for tools, fertilizers, harvested crops and other materials. Additional protection should be provided for the waterproofing layer, due to the frequent use of tools for harvesting and preparing soil.

Crop Selection

Not all crops are appropriate for living roofs. Crops that have a primary "tap root" which extends down vertically into the soil could potentially damage the waterproofing layer. These crops include corn, burdock, alfalfa, olives and many types of fruit trees. Because of the high cost of urban land, urban farms often focus on high-value crops that can be grown densely and harvested frequently, such as mixed lettuce greens.

Urban Agriculture Ordinance

The San Francisco Urban Agriculture Ordinance includes rules for small scale agriculture. Gardens on rooftops under 1 acre in size are considered "home gardens" and are an allowed "accessory use" under the Planning Code. Gardens that are more than one acre are allowed in certain zones of San Francisco under a conditional use permit. Home gardens are required to follow a few simple guidelines, such as:

- Setting back compost areas 3 feet from dwelling units and decks;
- Not using mechanized farm equipment;
- Limiting the sale of food products to the hours of 6 a.m. to 8 p.m; and
- Enclosing or screening farm equipment from sight.

Home gardeners are allowed to sell their home-grown produce either on-site or off-site. This produce could be sold to local stores, restaurants or other buyers. However, anyone who sells what they grow will be considered an agricultural business by the City of San Francisco, and may be subject to additional regulations.

Beekeeping

Bees are highly beneficial insects, providing local honey and pollination for edible crops and otherplants. Beekeeping is allowed in San Francisco without a permit, but is still subject to nuisance laws. San Francisco bee keepers should be knowledgeable about the complexities of beekeeping before installing a hive. See the San

Francisco Beekeepers Association's website for more information.

Pesticides and Fertilizers

The application of pesticides and fertilizers should be carefully considered on living roofs as they are susceptible to leaching off the roof and directly into the City's sewer system. Rooftop farmers are subject to the same laws governing pesticide use as other farmers, and should contact the agricultural commissioner for permit information.

It is recommended to use only slow-release organic fertilizers and compost for nutrient additions, and to use biological controls for pest management. Slow release fertilizers are designed to deliver a consistent level of plant nutrients at a rate that plants can actually use. Biological pest controls are organisms that naturally eat or inhibit specific pests, and can include insects, birds, fungi or plants. Predatory insects can be purchased and released directly into the garden or attracted by plants that provide habitat for them. Insectivorous birds such as chickadees and bluebirds can be attracted by providing appropriately sized nest boxes and birdbaths.

Irrigation

Irrigation systems for edible crops will need to be more flexible to account for periodic harvesting and replanting. Food production generally has a higher associated water use thanother plantings.

Notable Rooftop Farms

UNCOMMON GROUND Chicago

The Uncommon Ground restaurant in Chicago's Edgewater neighborhood became the first certified organic rooftop farm in North America in 2008. 30 varities of crops are grown on the 2,500 ft.^{2} deck, retrofitted to a 100+ year old building. The farm yields over 803 lbs. of produce per year for the restaurant below.

LUFA FARMS Montreal

LUFA Farm's 32,000 square foot rooftop greenhouse in Montreal's Ahuntsic district takes advantage of waste heat from the building below and rainwater to provide over 70 metric tons of food year-round to Montrealers. Vegetables are grown hydroponically and delivered the same day they are harvested.

Photos (top to bottom): 1. Uncommon Ground, by Zoran Orlic Photography, 2011 (cropped from original) 2. LUFA Farms Ahuntsic location, LUFA Farms, CC BY NA 2.0 (photo cropped).

Some alternate water sources (such as greywater) should not be used on edible crops due to the risk of disease transmission.

14. Construction

RECOMMENDATIONS

23 Coordinate trades to ensure efficient construction

24 Prioritize safety during construction and maintenance by following all applicable fall protection requirements

25 Avoid soil media compaction and rooftop stockpiling during construction activities

FOR MORE INFORMATION:

Green Roof Design and Installation Resource Manual (2013). Green Roofs for Healthy Cities.
Available from http://greeninfrastructurestore.com/Green-Roof-Design and-Installation.html

California Occupational Safety Administration
http://www.dir.ca.gov/dosh/

The NRCA Green Roof Systems Manual (2007). National Roofing Contractors Association
http://icbuildingsolutions.com/uploads/1/4/6/3/14638878/nrca_roof_ manual_.pdf

Living roof construction requires careful planning and coordination among the many trades involved. Properly executed construction will help to ensure a successful and safe project. Living roof construction can take from one day to several months to complete.

Safety

Working on a roof is dangerous, due to the risk of falling and the exposure to environmental conditions. These risks can be mitigated with fall protection measures or devices that physically prevent someone from falling off the roof, such as a parapet or a railing. The California Occupational Health and Safety Administration (Cal OSHA) requires certain levels of fall prevention or protection based on the height of the roof. Workers will need access to the roof during construction and during maintenance activities. If the roof is an accessible amenity, it will require parapets or railings. Extensive living roofs that are not designed for human occupation will have lower fall protection requirements than accessible living roofs that are designed as an amenity.

Trade Coordination and General Timeline

The work of the various trades involved in constructing the roof needs to be properly scheduled and coordinated. Mechanical components of the roof will be installed first. These include air conditioners, access stairways or hatches, vents, electrical conduits, water standpipes,

Living roof construction at Heron's Head Ecocenter. Photo courtesy Awie Smit, Habitat Gardens.

drainage piping, skylights, solar panel mounts, and other features. Next, the roofer will install the insulation and waterproofing layer. Insulation may not be necessary in every project, and may be installed above or below the waterproofing layer. Waterproofing must be installed so that all penetrations of the waterproofing layer are guaranteed to be watertight, including the roof drains. Some projects may elect to install a leak detection system below the waterproofing membrane. Photos of the waterproofing layer should be taken before the living roof components are installed, to provide a visual record. The final trade will be the living roof installer, who will begin by laying down the various components of the protection layer or root barrier, the drainage layer, filter fabric, edge restraints, and finally, the soil media. It is important that planting occurs soon after the soil is installed. Workers walking over the roof will compact the soil, inhibiting or delaying plant growth. Rainfall may also compact the soil media.

Materials Delivery

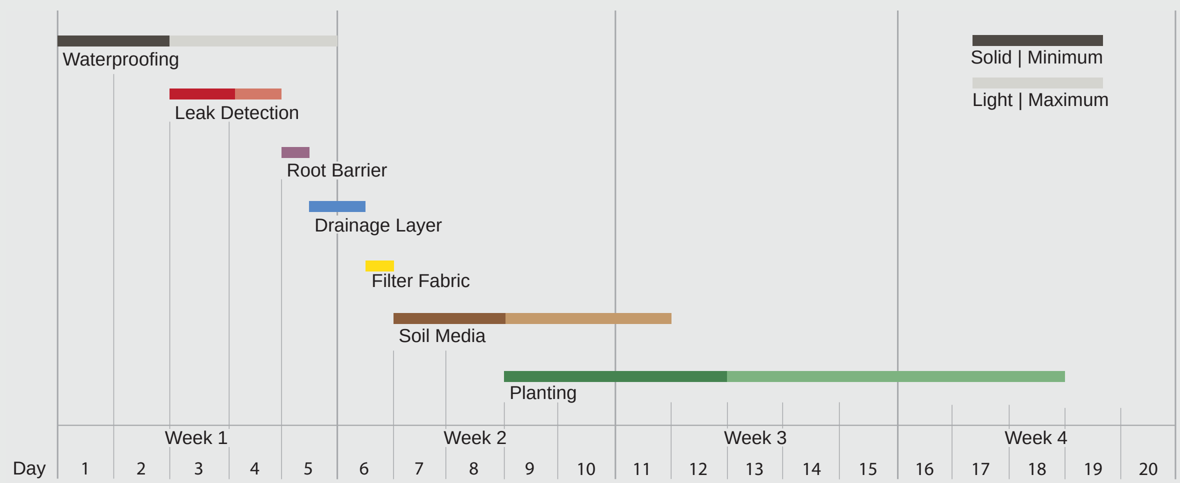
Materials and supplies can be delivered to the roof via cranes, conveyors, blowers, or hand carrying. Most materials should be installed immediately after delivery to the site, especially plant materials. Cranes can be expensive and disruptive to surrounding uses. Therefore, the time spent using cranes should be minimized. Soil is often delivered to the project site in super-sacks or truck beds. Living roof installers can lift soil to the roof by using a truck-based blower system. These systems suck soil from a truck and pump it to the roof using an air blower.

The stockpiling of materials on the roof itself should be minimized, in order to avoid over-loading it. The structural engineer should specify how much stockpiling is allowed.

Example Construction Timeline

10,000 FT.$^{2.}$ EXTENSIVE LIVING ROOF

TOTAL = 13 - 24 DAYS



Photos (left to right): Construction of Heron's Head EcoCenter, 1,2,3,4,5 and 6 courtesy Awie Smit, Habitat Gardens.

15. Maintenance

RECOMMENDATIONS

26 Design for the desired level of maintenance

27 Provide a detailed maintenance manual

28 Plan for ongoing maintenance

'AMA Plaza Green Roof Maintenance', by the Center for Neighborhood Technology, CC BY-SA 2.0

FOR MORE INFORMATION:

Design Guidelines and Maintenance Manual for Green Roofs in the Semi-arid and Arid West. (2010). Tolderlund, L.
http://www2.epa.gov/sites/production/files/documents/GreenRoofsSemiAridAridWest.pdf

Occupational Safety and Health Administration
29 CFR 1910 Subpart D (general industry standards) and 29 CFR 1926 Subpart M (construction standards).

Green Roof Maintenance. (2014). Columbia Green technologies.
http://columbia-green.com/wp-content/uploads/2014/08/CGT_Maintenance_July2014.pdf

Living roofs, like any other roof or landscaped area, require some regular and periodic maintenance in order to remain functional and perform their best. The level of maintenance required will vary depending on the design and size of the living roof. Extensive living roof's are often designed for lower maintenance, while intensive living roofs require maintenance similar to a garden or a park. There are two maintenance periods that will require somewhat different activities and frequency: establishment maintenance and long term maintenance. The establishment period can range from the first year after planting to the first two growing seasons. The establishment period encompasses the time required for the plants to acclimate to the environmental conditions of the roof, reach a minimum desirable size, establish a healthy root system and have a high chance of survival. Maintenance during the establishment period will be more frequent than during the long-term period. The following page lists the general maintenance activities that may occur on a living roof in San Francisco. It is not intended to override the instructions provided in the maintenance manual provided by the living roof installer, as these instructions should be more detailed and customized for the unique conditions of an individual roof.

Maintenance manual

The California Fire Code (2013) requires a maintenance manual be included with every living roof, detailing all of the expected maintenance activities and their frequency. The maintenance manual should be printed (and ideally laminated, or placed in a binder), along with the plant list, irrigation schedule, watering zones, and planting plan. The manual should then be given to the maintenance contractor or permanently placed in a highly visible location near the roof or roof entrance.

Human access and avoiding damage

The roof should be designed to facilitate maintenance activities providing necessary access for people, tools and equipment. Fall protection may also be required for maintenance personnel. Maintenance personnel should wear proper clothing, including close-toed shoes and gloves.

Maintenance tools that have a low risk of damaging the roof or penetrating the waterproofing membrane should be used. For example, hand trowels that have blunt tips, or are shorter than the growing media depth should be used instead of shovels, picks or sharp trowels. Maintenance personnel should be given an opportunity to read and reference the maintenance manual, and should be briefed on the depth of components of the roof and how to prevent damage to them. Maintenance personnel should avoid walking directly on soil and plant material, as this can cause compaction and plant damage. If there are frequently used pathways directly through the planted areas that were unanticipated in the initial design, structural soil support can be added to those areas to avoid compaction.

Selecting a maintenance contractor

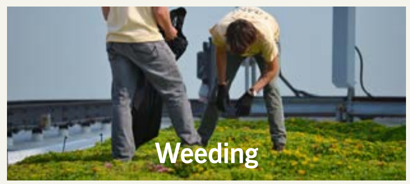
Living roof maintenance can be accomplished by the building owner (usually the case for small living roofs) or by a professional maintenance contractor. Where possible, a maintenance contractor with experience or training maintaining living roofs should be selected, as living roofs will have unique maintenance needs when compared to ground-level landscapes or typical roofs.

Maintenance costs

Maintenance costs will vary based on the frequency of maintenance and any unique conditions (such as difficult access). Many living roof installers will also offer a period of maintenance with their contract, usually during the establishment phase. This can be a good way for installers to ensure a successful project.

A properly maintained roof results in maximized benefits. San Francisco's dry summers mean that irrigation needs to be adjusted and optimized, and our wet, mild winters provide the perfect conditions for weeds to colonize the roof. Roof owners and designers should plan for some level of maintenance throughout the life of the living roof.

Typical Maintenance Activities

		FREQUENCY	TIME OF YEAR
	The irrigation schedule should be adjusted seasonally as plant's water requirements change. Check soil moisture then observe irrigation system to make adjustments and visually inspect for breaks or leaks.	At least 4 times per year	Seasonally
	Weeding should be done whenever weeds are observed, with special care taken to weed fire-breaks and other plant-free zones.	Monthly during establishment, periodically after	All year
	Soil should be tested yearly to determine nutrient levels. If necessary, organic, slow-release fertilizer should be added to replenish nutrients.	Yearly, starting one year after installation	Fall
	Roof drains should be inspected to make sure that they are free of debris and fully functioning. Secondary drains should be inspected as well.	Yearly	Fall
	Dead plant material or excessive growth should be removed when it grows into pathways or vegetation-free areas, or if a build-up of dry material presents a fire hazard.	At least 2 times per year	Late summer, Spring

Photos (from top to bottom): 1. 'Irrigation box', by Kerby Olsen, 2. 'AMA Plaza Green Roof Maintenance', by the Center for Neighborhood Technology, CC BY-SA 2.0 (cropped from original), 3. 'Fertilizer' © 2015, Green Roof Solutions, 4. 'Roof drain', by Kerby Olsen, 5. 'Deadheading', by Sue Trusty, © 2015 (cropped from original).

Common maintenance issues

Common living roof maintenance issues include wind scouring, dry or oversaturated plants, excessive weed growth, unhealthy plants and dead plants.

Wind scouring is a common condition on living roofs, but will vary by location. Wind can cause soil movement, plant desiccation, and miss-allocation of spray irrigation. The living roof designer should specify soil that is dense enough to resist wind uplift. Pre-vegetated *Sedum* mats can be a good choice for wind-prone areas, as they are unlikely to have exposed soil.

Excessive weeds can be caused by: Insufficient plant coverage, over watering, over-fertilization, or lack of maintenance during establishment. Some weeds are to be expected, as weed seeds are pervasive and can be carried to the roof by wind or bird droppings. Weed species can dominate portions of the roof, crowding out the desired plants and potentially creating a fire hazard.

Dry or oversaturated plants can be caused by a malfunctioning irrigation system. The growing media should not be fully saturated except after irrigation or rainfall. It is recommended to test the growing media moisture at various locations around the roof, with at least one test in each irrigation zone.

Dead plants can be caused by a variety of factors. It is normal for 10-15% of living roof plants to fail during the establishment period. Once established, continual die-off may be a sign of other issues, such as plant intolerance of environmental conditions or improper irrigation.

Unhealthy plants can also be caused by a variety of factors. The soil media may lack nutrients, leading to yellowing or stunted growth. Test the soil to determine if nutrient deficiencies exist.

Maintenance Troubleshooting

PROBLEM	POSSIBLE SOLUTION
Wind Scoured Soil	Construct wind barriers, replace wind intolerant species with more tolerant ones, or place ground covers, such as jute netting, on the soil surface.
Excessive Weeds	During the establishment phase, the roof should be weeded every other week to ensure that weeds do not become established and begin spreading seeds which will persist in the soil. Once the roof is established and proper plant coverage is achieved, weeds can be kept to a minimum by avoiding over-watering.
Dead Plants	Replace dead plants with new ones. It is normal for 10-15% of living roof plants to fail during the establishment period. Consult the designer if die-off continues.
Stunted Plants	Conduct a soil test to determine nutrient levels. Periodically replenish the nutrients in the soil through fertilization with slow-release organic fertilizer.
Dry or Over-watered Plants	Inspect the growing media moisture between waterings in the vicinity of the plants, and adjust the irrigation system timing. To inspect the moisture: dig down two inches into the growing media. The surface should be dry, but there should be some dampness at two inches (similar to a wrung-out sponge). If the media is fully saturated, reduce watering. If it is completely dry, increase watering slightly and re-test between the next two irrigation cycles.

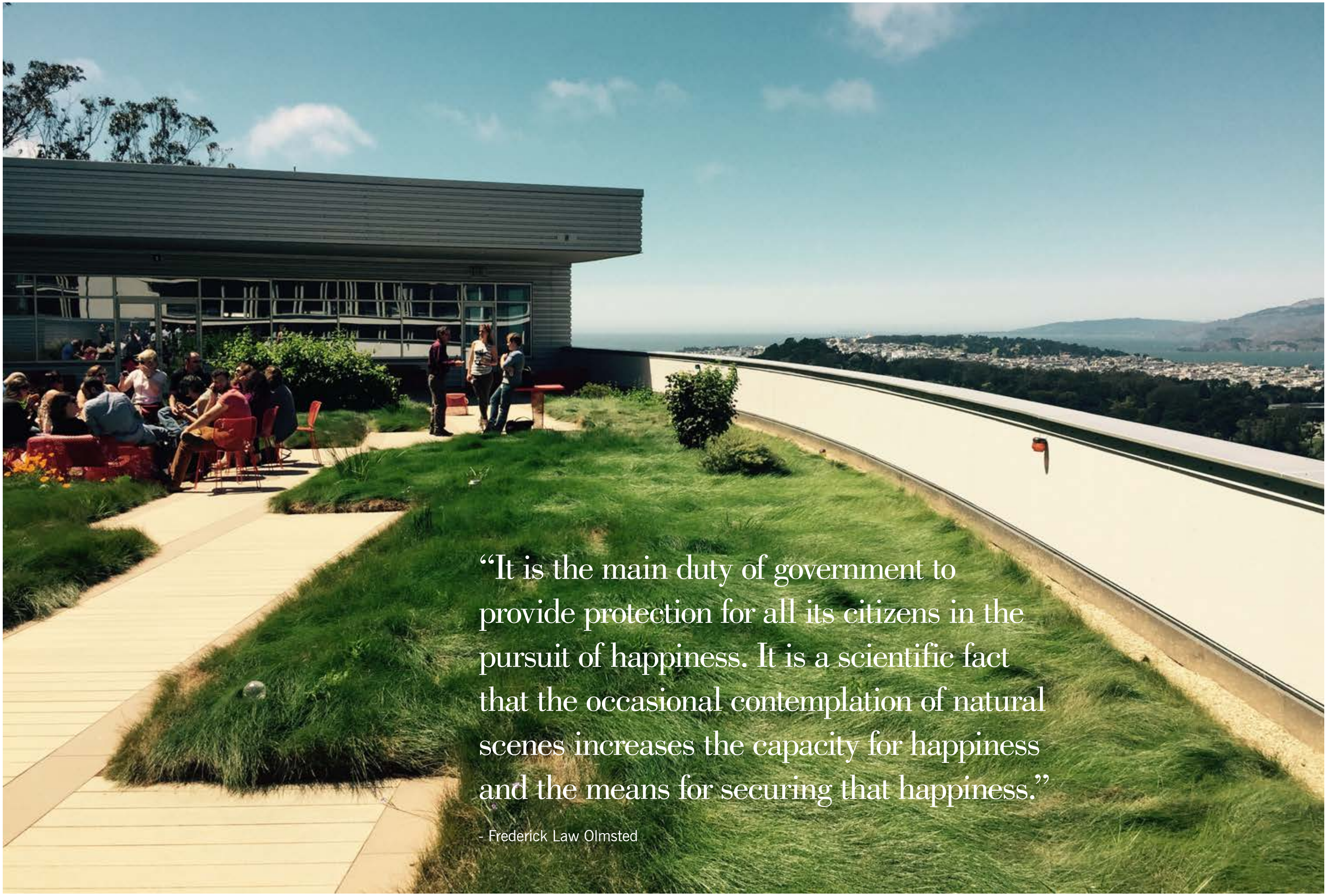


Photo: "U.C. San Francisco Ray and Dagmar Dolby Regeneration Medicine Building's living roof", by Kerby Olsen, 2015.

Appendix A: Photo Index

Page. Location on page, 'title', author and/or source, year.
Page i. 'California Academy of Sciences' by Kay Cheng, 2013.
Page iv. 'University of San Francisco Center for Science and Innovation' by Kay Cheng, 2014.
Page vi. '50 U.N. Plaza', by Laura Kudrizki, © 2013 The Registry.
Page 1. From top left to bottom right: 1. 'Heron's Head EcoCenter', Courtesy Awie Smit, 2. '38 Dolores', by Kay Cheng, 2014, 3. '1 South Van Ness', by Kerby Olsen, 2014, 4. 'Killdeer Nesting on Ellis Creek Water Recycling Facility in Petaluma, CA', by Symbiosis Ecotecture, 5. "U.C. San Francisco Ray and Dagmar Dolby Regeneration Medicine Building's living roof", by Kerby Olsen, 2015.
Page 2-3. From top left to bottom right: 1. 'Waterproofing at Heron's Head Ecocenter', courtesy Awie Smit, 2. '11" Inspection chamber', Green Roof Solutions © 2015, 3. 'RB 20 Root barrier', Green Roof Solutions © 2015, 4. 'Drainage panel', Green Roof Solutions, © 2015, 5. ''Geocomposite drain2', (link to source: https://upload.wikimedia.org/wikipedia/commons/d/de/Geocomposite_drain2.jpg) by Werner W Müller and Fokke Saathoff [CC BY 3.0 (http://creativecommons.org/licenses/by/3.0)], via Wikimedia Commons (cropped from original), 6. 'Hoffman Bonsai Soil Mix', (link to source: https://upload.wikimedia.org/wikipedia/commons/3/3e/Hoffman_Bonsai_Soil_Mix.jpg) by Ragesoss (Own work), CC BY-SA 3.0 or GFDL (http://www.gnu.org/copyleft/fdl.html)], via Wikimedia Commons (cropped from original), 7. 'Drip irrigation', photo courtesy Hunter Industries, 8. 'Sedums', by Kay Cheng, 9. 'Edge restraint', © 2015, Green Roof Solutions.
Page 4. From left to right: 1. 'White roof and skylights on Las Vegas, Nev. Walmart', Walmart Corporation © 2007, CC By SA 2.0, (link to source: https://www.flickr.com/photos/walmartcorporate/5258813444/in/photostream/), 2. '50 UN Plaza Solar Panels', by Kerby Olsen, 2014, 3. 'Blue Roof', courtesy Gowanus Canal Conservency.
Page 7. From top left to bottom right: 1. 'Living roof tour', by Kay Cheng, 2014, 2. 'Sewer Overflow Sign Sloat', by Tom Preet, Oceanview Bulletin, 3. '38 Dolores roofdeck', by Kay Cheng, 2014, 4. STEM Kitchen + Garden, by Dan Gilette, 2015.
Page 9. From left to right: 1. '38 Dolores living roof', by Kay Cheng, 2014, 2. 'Matarozzi Pelsinger living roof', by Kay Cheng, 2014.
Page 10. 'Planning Information Counter', by San Francisco Planning Department.
Page 14. 'San Francisco Planning department living roofs map', screenshot by Kerby Olsen.
Page 15. '50 UN Plaza living roof', by Anne Brask, 2014.
Page 16. From left to right: 1. 'Heron's Head EcoCenter', by Kay Cheng, 2013, 2. 'California Academy of Sciences', by Kerby Olsen, 2014, 3. '1 South Van Ness', by Kerby Olsen, 2014, 4. STEM Kitchen + Garden, by Dan Gilette, 201
Page 17. '1 South Van Ness Living Roof', by Kerby Olsen, 2014.
Page 18. 'Heron's Head EcoCenter', by Kay Cheng, 2014.
Page 19. 'California Academy of Sciences', by Kay Cheng, 2013.
Page 20. '1 South Van Ness', by Kay Cheng, 2013.
Page 21. STEM Kitchen + Garden, by Petar Iliev, 2015.
Page 22. Top to bottom: 1. 'Richmond Olympic Oval intern View', (link to source: https://upload.wikimedia.org/wikipedia/commons/f/f3/Richmond_Olympic_Oval_intern_View.jpg) by Thelastminute (Duncan Rawlinson), CC BY 2.0, via Wikimedia Commons (cropped from original), 2. 'Water proofing installation', photo Courtesy Awie Smit, Habitat Gardens, 3. 'Drainage panel', © 2015, Green Roof Solutions.
Page 23. Top-left to bottom-right: 1. 'Hoffman Bonsai Soil Mix', (link to source: https://upload.wikimedia.org/wikipedia/commons/3/3e/Hoffman_Bonsai_Soil_Mix.jpg) by Ragesoss (Own work), CC BY-SA 3.0 or GFDL (http://www.gnu.org/copyleft/fdl.html)], via Wikimedia Commons (cropped from original), 2. 'Micro-spray irrigation', photo courtesy Hunter Irrigation. 3. 'Western Columbine' (Aquilegia formosa), (link to source: https://upload.wikimedia.org/wikipedia/commons/b/b5/Western_columbine_%28Aquilegia_formosa%29_%286048472516%29.jpg) by Franco Folini from San Francisco, USA, CC BY-SA 2.0, via Wikimedia Commons/ cropped from original, 4. CA Native Bumble bee, 5. STEM Kitchen + Garden, by Petar Iliev, 6. 'Construction at Heron's Head EcoCenter', photo courtesy Awie Smit, Habitat Gardens. 6. 'AMA Plaza Green Roof Maintenance', (link to source: https://www.flickr.com/photos/centerforneighborhoodtechnology/14522635329) by The Center for Neighborhood Technology, CC BY 2.0 (cropped from original).
Page 24. Top left: 'Richmond Olympic Oval intern View', (link to source: https://upload.wikimedia.org/wikipedia/commons/f/f3/Richmond_Olympic_Oval_intern_View.jpg) by Thelastminute (Duncan Rawlinson), CC BY 2.0, via Wikimedia Commons (cropped from original).
Page 27. 'A roof drain', photo by Kerby Olsen, 2014.
Page 28. 'Soil media', by Kerby Olsen, 2015.
Page 29. Top to bottom: 1. Air, 2. 'Scoria material on Tenerife' (link to source: https://upload.wikimedia.org/wikipedia/commons/7/7e/Scoria_material_on_Tenerife_in_2014_%281%29.JPG) by Chmee2 (Own work), CC BY-SA 3.0, (cropped from original), 3. 'Blue water, Lake Tahoe', (link to source: https://upload.wikimedia.org/wikipedia/commons/1/1c/Blue_water%2C_Lake_Tahoe.jpg) by Downtowngal (Own work), CC BY-SA 3.0, (cropped from original), 4. 'Compost-dirt', (link to source: https://upload.wikimedia.org/wikipedia/commons/5/53/Compost-dirt.jpg) by normanack [CC BY 2.0 (http://creativecommons.org/licenses/by/2.0)], via Wikimedia Commons, (cropped from original) 5.''Geocomposite drain2', (link to source: https://upload.wikimedia.org/wikipedia/commons/d/de/Geocomposite_drain2.jpg) by Werner W Müller and Fokke Saathoff [CC BY 3.0 (http://creativecommons.org/licenses/by/3.0)], via Wikimedia Commons (cropped from original).
Page 30. 'Micro-spray irrigation', photo courtesy Hunter Industries.
Page 31. From left to right: 1. 'Drip tubing', photo courtesy Hunter Industries, 2. 'Micro-spray irrigation', photo courtesy Hunter Industries, 3. 'Eco-mat installation', photo courtesy Hunter Industries.
Page 32. From left to right: 1. 'Refraction of Golden Gate Bridge in rain droplets', (link to source: https://upload.wikimedia.org/wikipedia/commons/0/05/Refraction_of_Golden_Gate_Bridge_in_rain_droplets.jpg) by Brocken Inaglory (Own work) CC BY-SA 3.0, (cropped from original), 2. 'Showerhead', (link to source: https://www.flickr.com/photos/gcfairch/4367100484) by Geoffrey Fairchild, CC BY 2.0, (cropped from original), 3. 'Purple pipe', (link to source: https://www.flickr.com/photos/johnloo/3645996260) by John Loo, CC BY 2.0
Page 34. 'California Poppies at UCSF', by Kerby Olsen, 2015.
Page 35. Top-left to bottom-right: 1. 'Achillea millefolium capitula', (link to source: https://upload.wikimedia.org/wikipedia/commons/6/68/Achillea_millefolium_capitula_2002-11-18.jpg) © by Curtis Clark, CC BY-SA 2.5

(cropped from original), 2. ‘Arctostaphylos uva-ursi’, (link to source: https://it.wikipedia.org/wiki/Arctostaphylos_uva-ursi#/media/File:Arctostaphylos-uva-ursi.JPG) by Sten Porse, CC BY-SA 3.0, (cropped from original), 3. ‘Armeria maritima’, ©2009 Ron Wolf, 4. ‘California poppy’, by Kerby Olsen, 5. ‘California fuschia’, by Kerby Olsen, 6. ‘California fescue at 38 Dolores’, by Kay Cheng, 7. ‘Beach strawberry at 38 Dolores’, by Kay Cheng, 8. ‘Spreading rush’ by Kerby Olsen, 9. ‘Lupinus Bicolor’, (link to source: https://upload.wikimedia.org/wikipedia/commons/d/d2/Lupinus_bicolor.jpg) by Cau-Vi Phung (Author (Copyright holder)), via Wikimedia Commons, CC BY-SA 3.0 (cropped from original), 10. ‘Sticky monkey flower’, by Kay Cheng, 11. ‘Baby blue-eyes’, by Kerby Olsen, 12. ‘Self-heal’, (link to source: https://upload.wikimedia.org/wikipedia/commons/5/5d/Prunella_vulgaris_two.jpg) by Júlio Reis (Own work)CC BY-SA 3.0, (cropped from original), 13. ‘Blue-eyed grass’, by Patrick Race, 14. ‘Muhlenbergia rigens form’, (link to source: https://upload.wikimedia.org/wikipedia/commons/e/ed/Muhlenbergia_rigens_form.jpg) by Stan Shebs [GFDL (http://www.gnu.org/copyleft/fdl.html), CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0) or CC BY-SA 2.5 (http://creativecommons.org/licenses/by-sa/2.5)], via Wikimedia Commons (cropped from original), 15. ‘Biting Stonecrop close 800’, (link to source: https://upload.wikimedia.org/wikipedia/commons/e/e1/Biting_stonecrop_close_800.jpg) by Sannse, CC BY-SA 3.0, (cropped from original), 16. ‘Sedum Album a1’, (link to source: https://upload.wikimedia.org/wikipedia/commons/5/5b/Sedum_album_a1.jpg) by Jerzy Opioła (Own work), CC BY-SA 2.5, (cropped from original), 17. ‘Biting stonecrop’, (link to source: https://upload.wikimedia.org/wikipedia/commons/e/e1/Biting_stonecrop_close_800.jpg) by beautifulcataya, CC BY-SA 3.0, (cropped from original), 18. ‘Sedum oreganum 4’, (link to original: https://upload.wikimedia.org/wikipedia/commons/9/96/Sedum_oreganum_4.jpg) by Stan Shebs, CC BY-SA 3.0, (cropped from original), 19. ‘Sedum spathulifolium ‘Campbell Lake’’, (link to source: https://www.flickr.com/photos/john_d_rusk/9780469752/in/photostream/) by John Rusk, CC BY-NC-SA 2.0, (cropped from original), 20. ‘Sedum spurium’, (link to source: https://www.flickr.com/photos/51628428@N00/1693827369/in/photostream/) by Ezequiel Coelho, CC BY-NC-ND 2.0, (cropped from original).
Page 36. ‘Bee box’, by Kendra Hauser, 2015.
Page 37. Top-left to bottom-right: 1. ‘Female Anna’s hummingbird in flight’, (link to source: https://upload.wikimedia.org/wikipedia/commons/8/8e/Annas_Hummingbird_%28female_in_flight%29.jpg) by Noël Zia Lee, CC BY 2.0, (modified from original, background removed), 2. ‘California fuschia’, by Kerby Olsen, 3. ‘Salvia spathacea’, (link to original: https://www.flickr.com/photos/briweldon/5605336914) by Bri Weldon, CC BY 2.0, (cropped from original), 4. ‘Arctostaphylos uva-ursi’, (link to source: https://it.wikipedia.org/wiki/Arctostaphylos_uva-ursi#/media/File:Arctostaphylos-uva-ursi.JPG) by Sten Porse, CC BY-SA 3.0, (cropped from original), 5. ‘Heron’s Head Ecocenter branch’, photo courtesy Awie Smit, 6. California bumble bee, 7. ‘Lupinus Bicolor’, (link to source: https://upload.wikimedia.org/wikipedia/commons/d/d2/Lupinus_bicolor.jpg) by Cau-Vi Phung (Author (Copyright holder)), via Wikimedia Commons, CC BY-SA 3.0 (cropped from original), 8. ‘Eriogonum parvifolium 3’, (link to source: https://upload.wikimedia.org/wikipedia/commons/2/26/Eriogonum_parvifolium_3.jpg) by Stan Shebs [GFDL (http://www.gnu.org/copyleft/fdl.html), CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0) or CC BY-SA 2.5 (http://creativecommons.org/licenses/by-sa/2.5)], via Wikimedia Commons, (cropped from original), 9. ‘Achillea millefolium bloem’, (link to source: https://upload.wikimedia.org/wikipedia/commons/7/77/Achillea_millefolium_bloem.jpg) by Pethan from nl [GFDL (http://www.gnu.org/copyleft/fdl.html) or CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/)], via Wikimedia Commons, (cropped from original), 10. ‘California Academy of Sciences dirt mound’, by Kerby Olsen. 11. “Coastal” Bramble Hairstreak Butterfly, Callophrys dumetorum viridis, by “Mike” Michael L. Baird, (https://www.flickr.com/photos/mikebaird/6965353272), CC BY SA 2.0, (modified from original), 12. ‘Deerweed 01’, (link to source: https://www.flickr.com/photos/tomhilton/5750339785) by Tom Hilton, 2011, CC BY 2.0, (cropped from original), 13. ‘Armeria maritima’, ©2009 Ron Wolf’, (cropped from original), 14. ‘Erigeron glaucus (Seaside Daisy)’ (link to source: https://www.flickr.com/photos/jkirkhart35/14361327758) by Jerry Kirkhart, 2014, CC BY 2.0, (cropped from original), 15. ‘Pond on USF roof’, by Kerby Olsen.
Page 38. ‘STEM Kitchen + Garden’, by Anne Brask, 2015.
Page 39. From top to bottom: 1. ‘STEM Kitchen + Garden’, by Daniel Gilette, 2015, 2. ‘View of Common Ground rooftop farm’, by Zoran Orlic photography, 2011, 3. ‘Aerial photo of LUFA Farms Ahuntsic location’, (link to source: http://lufa.com/en/our-farms.html) © LUFA Farms, CC BY SA 2.0., (cropped from original).
Page 40. ‘Construction’, photo courtesy Awie Smit, Habitat Gardens.
Page 40. ‘Living roof construction at Heron’s Head Ecocenter’, courtesy Awie Smit, Habitat Gardens.
Page 41. Left to right: photos 1,2,3,4,5 and 6 courtesy Awie Smit, Habitat Gardens.
Page 42. ‘AMA Plaza Green Roof Maintenance’, by the Center for Neighborhood Technology, CC BY-SA 2.0, (cropped from original).
Page 43. From top to bottom: 1. ‘Irrigation box’, by Kerby Olsen, 2. ‘‘AMA Plaza Green Roof Maintenance’, (link to source: https://www.flickr.com/photos/centerforneighborhoodtechnology/14522635329) by The Center for Neighborhood Technology, CC BY 2.0 (cropped from original), 3. ‘Fertilizer’, © 2015, Green Roof Solutions, 4. ‘Roof drain’, by Kerby Olsen, 5. ‘Deadheading’, (link to source: http://thetrustygardener.com/blog/2010/06/10/deadheading/) by Sue Trusty, © 2015.
Page 45.“U.C. San Francisco Ray and Dagmar Dolby Regeneration Medicine Building’s living roof”, by Kerby Olsen, 2015.

Links to creative commons licenses:
Attribution 2.0 Generic (CC BY 2.0): https://creativecommons.org/licenses/by/2.0/legalcode
Attribution-ShareAlike 2.0 (CC BY-SA 2.0): https://creativecommons.org/licenses/by-sa/2.0/legalcode
Attribution 2.5 Generic (CC BY 2.5): http://creativecommons.org/licenses/by-sa/2.5/legalcode
Attribution-ShareAlike 2.5 (CC BY-SA 2.5): http://creativecommons.org/licenses/by-sa/2.5/legalcode
Attribution 3.0 Generic (CC BY 3.0): https://creativecommons.org/licenses/by-sa/3.0/legalcode
Attribution-ShareAlike 3.0 (CC BY-SA 3.0): https://creativecommons.org/licenses/by-sa/3.0/legalcode

Appendix B: Additional Resources

Costs and Benefits

The Benefits and Challenges of Green Roofs on Public and Commercial Buildings. (2011). U.S. General Services Administration.
http://www.gsa.gov/portal/mediaId/158783/fileName/The_Benefits_and_Challenges_of_Green_Roofs_on_Public_and_Commercial_Buildings.action

Permitting

San Francisco Department of Building Inspection
http://www.sfdbi.org

San Francisco Public Utilities Commission
http://www.sfwater.org

San Francisco Planning Department
http://www.sf-planning.org

Permit Application Intake Checklist
http://www.sf-planning.org/Modules/ShowDocument.aspx?documentid=8507

Roof Decks Handout
http://www.sf-planning.org/index.aspx?page=2802

Design

Green Roofs For Healthy Cities. Green Roof Professionals.
http://www.greenroofs.org/index.php/membership/findagreenroofpro

San Francisco Living Roof Map and Database
http://www.sf-planning.org/livingroof

Green Roof Design and Installation. (2013). Green Roofs for Healthy Cities.
Available from http://greeninfrastructurestore.com

Property Loss Prevention Sheet for Green Roof Systems. (2007). Factory Mutual Insurance Company.
http://www.ci.berkeley.ca.us/uploadedFiles/Planning_and_Development/Level_3_-_Energy_and_Sustainable_Development/Factory%20Mutual%20Green%20Roof%20System.pdf

Guidelines for the Planning, Installation and Maintenance of Green Roofing. (2008). The German Landscape Research, Development and Construction Society (FLL).
Available from http://www.fll.de/shop/english-publications.html

Design Guidelines and Maintenance Manual for Green Roofs in the Semi-arid and Arid West. (2010). Tolderlund, L.
http://www2.epa.gov/sites/production/files/documents/GreenRoofsSemiAridAridWest.pdf

Structural

ASTM Technical Guide E2397 - Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems

Tapping the Potential of Urban Rooftops. (2007). Bay Localize.
http://www.baylocalize.org/files/Tapping_the_Potential_Final.pdf

Waterproofing

Green Roof Waterproofing and Drainage Manual. Green Roofs for Healthy Cities.
Available from http://greeninfrastructurestore.com/Green-Roof-Waterproofing-and-Drainage.html

Water retention

ASTM Technical Guides
E2398 - Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Vegetative (Green) Roof Systems

E2788 - Specification for Use of Expanded Shale, Clay and Slate (ESCS) as a Mineral Component in the Growing Media and the Drainage Layer for Vegetative (Green) Roof Systems

San Francisco Stormwater Design Guidelines
http://www.sfwater.org/Modules/ShowDocument.aspx?documentID=2779

Growing media

ASTM Technical Guide E2788 - Specification for Use of Expanded Shale, Clay and Slate (ESCS) as a Mineral Component in the Growing Media and the Drainage Layer for Vegetative (Green) Roof Systems

Green Roof Plants and Growing Media Manual. Green Roofs for Healthy Cities.
Available from http://greeninfrastructurestore.com/Green-Roof-Waterproofing-and-Drainage.html

Irrigation

San Francisco Water Efficient Landscape
http://sfwater.org/index.aspx?page=689

Gardens and Landscapes
www.sfwater.org/landscape

A Guide to Drip Irrigation. The Urban Farmer Store.
http://www.urbanfarmerstore.com/pdflibrary/drip-irrigation/

Plants

San Francisco Green Connections
http://greenconnections.sfplanning.org

San Francisco Plant Finder
http://sfplantfinder.org/about.html

Green Roof Plants: A Resource and Planting Guide. (2006). Snodgrass, E.C., and Snodgrass, L.L.

ASTM E2400 Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems
http://www.astm.org/Standards/E2400.htm

Habitat

Natural San Francisco
http://www.sfenvironment.org/biodiversity

San Francisco Urban Forest Plan
http://www.sf-planning.org/ftp/files/plans-and-programs/planning-for-the-city/urban-forest-plan/Urban_Forest_Plan_Final-092314WEB.pdf

California Academy of Sciences Living Roof Plantlist
https://www.inaturalist.org/guides/1556

Urban Agriculture

Starting a Garden or Urban Farm in San Francisco
http://sfwater.org/modules/showdocument.aspx?documentid=1907

San Francisco Urban Agriculture Zoning Ordinance
http://www.sfbos.org/ftp/uploadedfiles/bdsupvrs/ordinances11/o0066-11.pdf

San Francisco Urban Agriculture Alliance
http://www.sfuaa.org/

San Francisco Beekeepers Association
http://www.sfbee.org

Construction

Green Roof Design and Installation Resource Manual (2013). Green Roofs for Healthy Cities.
Available from http://greeninfrastructurestore.com/Green-Roof-Design and-Installation.html

California Occupational Safety Administration
http://www.dir.ca.gov/dosh/

The NRCA Green Roof Systems Manual (2007).National Roofing Contractors Association
http://icbuildingsolutions.com/uploads/1/4/6/3/14638878/nrca_roof_manual_.pdf

Maintenance

Design Guidelines and Maintenance Manual for Green Roofs in the Semi-arid and Arid West. (2010). Tolderlund, L.
http://www2.epa.gov/sites/production/files/documents/GreenRoofsSemiAridAridWest.pdf

Occupational Safety and Health Administration
29 CFR 1910 Subpart D (general industry standards) and
29 CFR 1926 Subpart M (construction standards).

Green Roof Maintenance. (2014). Columbia Green technologies.
http://columbia-green.com/wp-content/uploads/2014/08/CGT_Maintenance_July2014.pdf

Appendix C

BUILDING CODE REQUIREMENTS FOR Living Roofs

Disclaimer: *This list of relevant code sections is not intended to grant permit approval, but should be consulted as a starting point to ensure that your living roof project adheres to relevant building codes. Additional or fewer code requirements may apply. Your living roof approval is ultimately subject to the discretion of the City and County of San Francisco.*

General Description of Code Requirement	Specific Numeric Value (if applicable)	Reference Code Section
SIZE AND CLEARANCE		
1a. Maximum area of contiguous living roof.	15,625 sq. ft.	(CFC) 317.2
1b. Maximum length/width for any side of living roof area.	125 ft.	(CFC) 317.2
1c. Minimum separation between living roof areas.	6 ft.	(CFC) 317.2
2. Minimum separation between vegetation and building walls or rooftop mechanical equipment.	6 ft.	(CFC) 317.3
STRUCTURAL LOADING		
3. Weight of all living roof layers shall be considered as “dead load” and shall be computed on the basis of saturated soil.		(CBC) 202 (CBC) 1607.12.3.1
4. Minimum uniform live load for occupiable living roofs.	100 psf	(CBC) Table 1607.1
5. Minimum uniform live load for non-occupiable living roofs.	20 psf	(CBC) 1607.12.3.1
5b. Minimum concentrated live load for non-occupiable living roofs.	300 lbs	(CBC) Table 1607.1
FIRE SUPPRESSION		
6. Buildings with standpipe systems shall extend the system to the level of the living roof.		(CFC) 905.3.8
7. Supplemental irrigation shall be provided to keep plants alive and dry foliage to a minimum.		(CFC) 317.4.1
8. Excess biomass (i.e. overgrown vegetation, leaves, and dead plant material) shall be removed not less than two times per year.	at least 2X per year	(CFC) 317.4.2
EGRESS AND ACCESSIBILITY		
9a. In buildings 4 or more stories above grade, a stairway shall extend to the roof, with access through a stair penthouse.		(CFC) 1009.16.1
9b. For non-occupiable roofs, access is permitted through a roof hatch or trap door, and alternating tread device.		(CFC) 1009.16.1
10. An accessible path of travel shall be provided to occupiable living roof areas.	roof hatch area $\geq$ 16 sq. ft.	(CBC) 11B - 202.4
11. Minimum guard height around living roofs, and minimum opening size in guard so that a sphere may not pass through.	42 in. high guard, 21 in. diameter sphere	(SFBC) 1013.2 & 1013.3, exception #2

Acronyms: California Fire Code (CFC), California Building Code (CBC), California Plumbing Code (CPC), San Francisco Building Code (SFBC), San Francisco Planning Code (SFPC), Pounds per square foot (PSF), Feet (ft.), Square feet (sq. ft.), Inches (in), lbs (pounds)

General Description of Code Requirement	Specific Numeric Value (if applicable)	Reference Code Section
12. Disabled access may need to be provided for accessible living roofs. Multiple exceptions apply.		(CBC) Ch. 11B
DRAINAGE		
13. Roofs shall provide primary and secondary drainage using appropriate materials.		(CPC) 1101.11 & 1105
14. Drainage can be sized based on the controlled flow and storage of stormwater on the roof, so long as the requirements of Sec. 1108 are met.		(CPC) 1108
15. All new storm drainage components shall be tested through an approved procedure to disclose leaks and defects.		(CPC) 1109
IRRIGATION		
16. Greywater systems for irrigation use are subject to the requirements of Ch. 16.		(CPC) Ch. 16
17. Recycled water systems for irrigation use are subject to the requirements of Ch. 16A.		(CPC) Ch. 16A
18. Rainwater harvesting systems for irrigation use are subject to the requirements of Ch. 17.		(CPC) Ch. 17
19. Living roofs > 1,000 sq. ft. are subject to the Water Efficient Irrigation ordinance.	roofs ≥ 1,000 sq. ft.	SF Administrative Code Ch. 63
URBAN AGRICULTURE		
20. Compost areas must be setback from dwelling units.	3 ft.	(SFPC) Sec. 102.35
21a. Agricultural products may not be stored next to structures or combustible materials.	horizontal separation equal to height of pile.	(CFC) 5203.4
21b. Agricultural stacks shall be limited to piles of 100 tons each.	stacks separated by minimum 20 ft.	(CFC) 5203.4
PLANNING AND LAND USE		
22. Land use regulations for urban and rooftop agriculture.		(SFPC) Sec. 102.35
23. Accessible living roofs are subject to requirements for roofdecks.		(SGBC) Ch. 15, Sec. 1509.6
24. Living roofs may satisfy requirements for usable open space.		(SFPC) Article 1.2, Sec. 135
25. Maximum allowable height for rooftop landscape features, other than vegetation.	4 ft.	(SFPC) Article 2.5, Sec. 260

Acronyms: California Fire Code (CFC), California Building Code (CBC), California Plumbing Code (CPC), San Francisco Building Code (SFBC), San Francisco Planning Code (SFPC), Pounds per square foot (PSF), Feet (ft.), Square feet (sq. ft.), Inches (in), lbs (pounds)

Appendix D

DECLARATION FORM
Living Roofs

When submitting for a building permit on a project that contains a living roof, please also include this form with your submittal.

NAME	EMAIL	DATE
Project Address		block/lot(s)
CASE NO./PERMIT NO. IF NONE, CHECK HERE: ☐		

Have you consulted a Certified Green Roof Professional (GRP)? *(A GRP can help ensure that your project will have the greatest chance for success. A list of local GRPs can be found on the Green Roofs for Healthy Cities website: www.greenroofs.org)*
☐ YES ☐ NO

PROJECT DESCRIPTION

1. Total Roof Area: ______________________ (sq. ft.)

2. Estimated Vegetated Area: ______________________ (sq. ft.)

3. Living Roof System Type (select one): Modular Tray-Based system / Built-Up Layers

4. Depth of Growing Media: ______________________ (list as range, i.e. 10-12")

5. Will the roof be occupiable? (circle one) Y / N 6. Will it be accessible to the public? Y / N

7. Please list the different professionals involved with the project: (as applicable)
   - Project Architect: ______________________
   - Landscape Architect: ______________________
   - Contractor/Installer: ______________________
   - Plant Supplier: ______________________
   - Maintenance Team: ______________________

8. What is the overall goal for the living roof, or what benefits are you hoping to maximize?

____

____

____

____

9. Expected completion date: ______________________

SAN FRANCISCO

LIVING ROOF MANUAL

Questions? Please refer to the San Francisco Planning Department's Living Roof Website:

WWW.SF-PLANNING.ORG/LIVINGROOF