Functional Green
Studies, Analyses, Rationale

August 18, 2022

A compilation of the papers produced by the CodeNEXT consultant team

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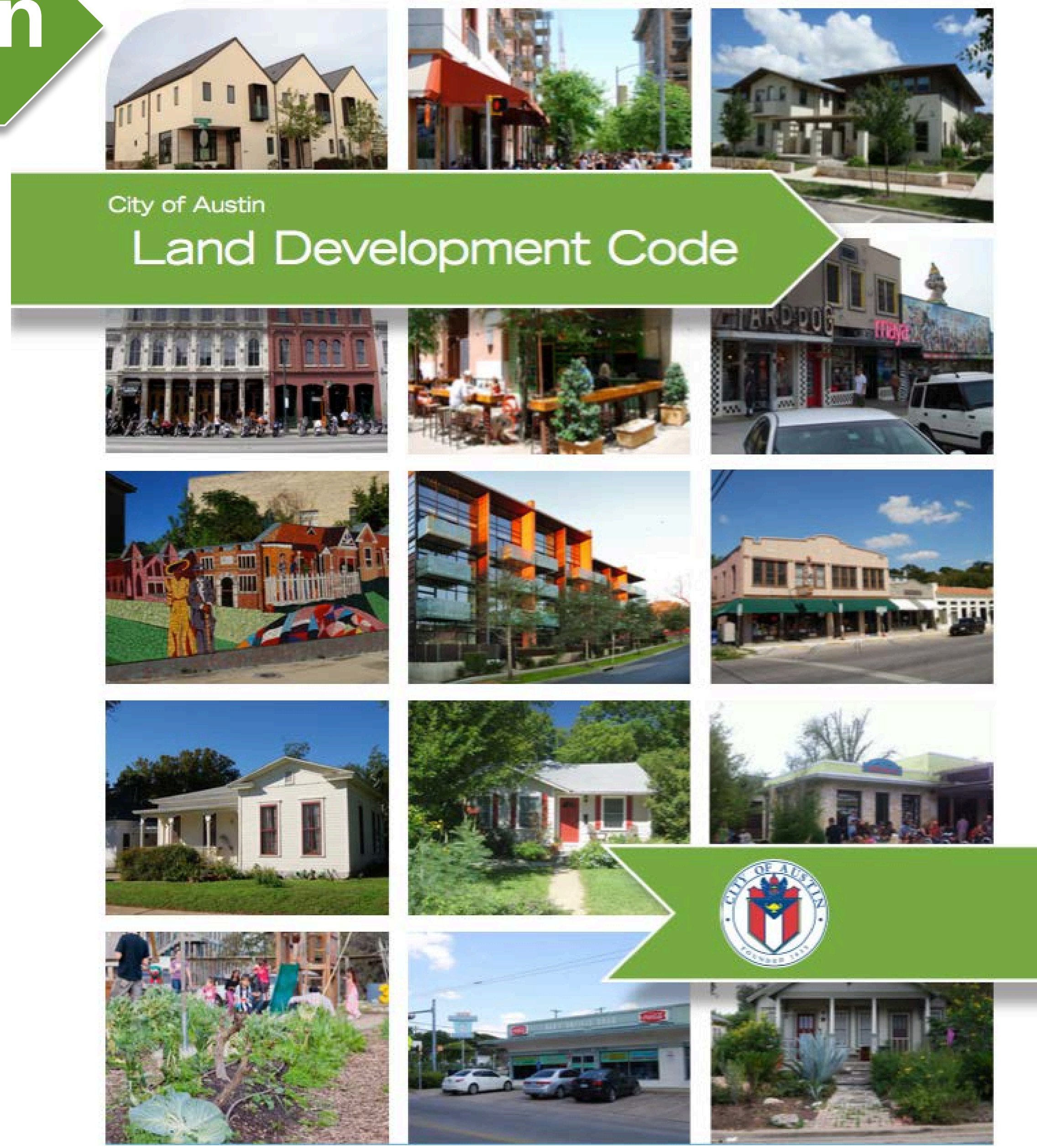
Functional Green



Meeting purpose = Share progress

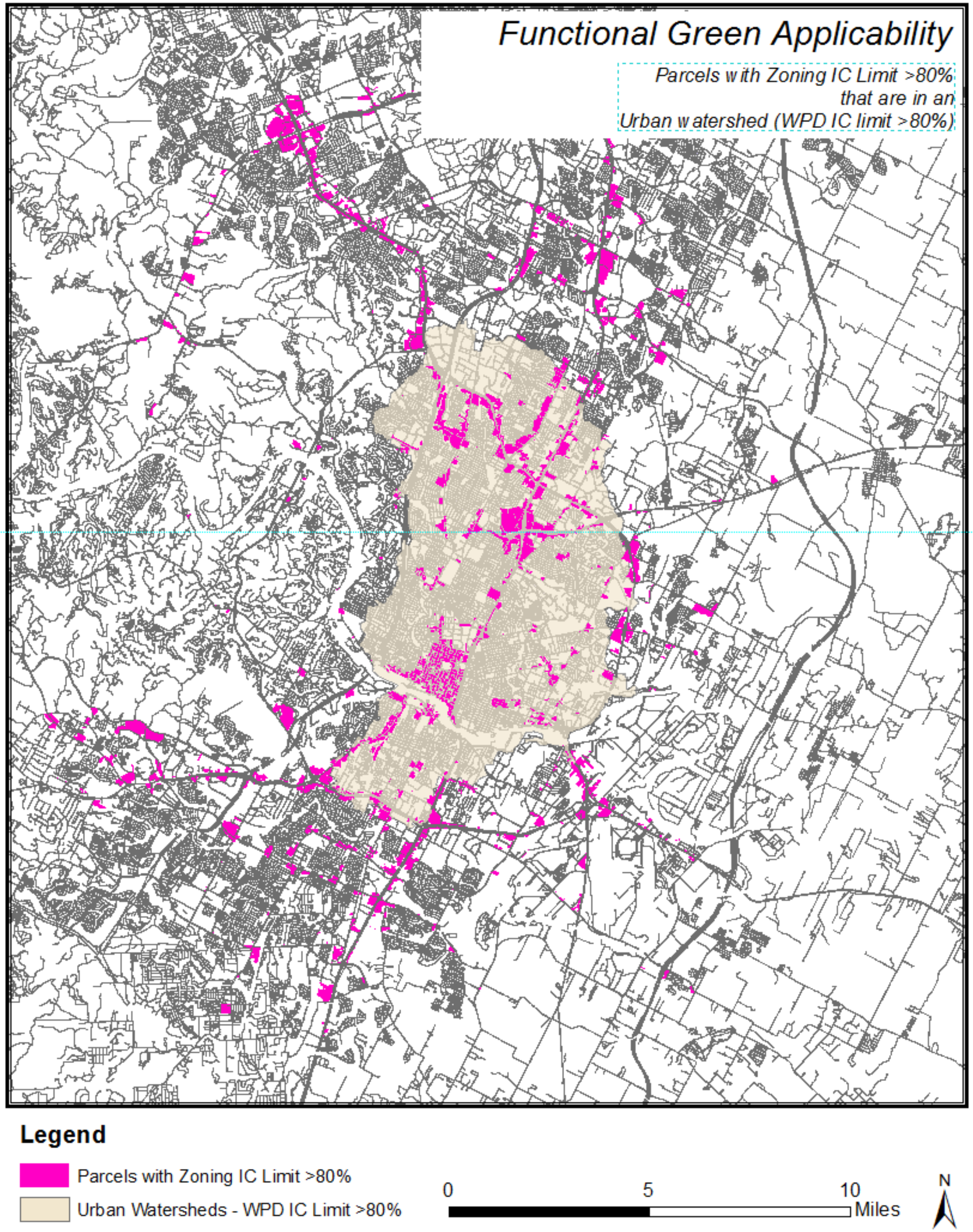
- Case study findings. Case study scores are relative to each other. This information informs the target score and tests the landscape element weights. Landscape elements will continue to be tested with the proof of concept work.
- Landscape element overview
- Next steps & Timeline
- Question & Answer
- Set date for follow up meeting after staff has time to discuss internally.
  - 12/15 - 1 to 5
  - 12/14 – all day

What are the goals of Functional Green?

1) **Integrate nature** into parcels where building cover or other impervious surfaces limit what the standard landscape code can accomplish.

1) Develop a **planning tool** that is **flexible and provides ecological benefits** comparable to those required in the standard landscape code.

1) Provide a **program** that is **straight forward** and **easy to implement and review**.


Functional Green Applicability
Parcels with Zoning IC Limit >80%
that are in an
Urban watershed (WPD IC limit >80%)
Legend
Parcels with Zoning IC Limit >80%
Urban Watersheds - WPD IC Limit >80%
0
5
10
Miles
N

Functional Green Development Process

- Identified the primary ecosystem services
  - Microclimate regulation and mitigation of urban heat island effects
  - Carbon storage and sequestration
  - Air pollutant removal
  - Stormwater retention and runoff reduction
  - Water filtration
  - Biodiversity benefits
  - Human health and well-being benefits

- Identified the landscape elements most likely to occur in dense urban landscapes
  - Trees
  - Planting beds
  - Green roofs
  - Rain gardens
  - Vegetated walls
  - Porous paving
  - Cisterns
  - Bonus points (pollinator friendly gardens, reduce potable water use etc…)

Functional Green Development Process

- **Literature review** which includes research from **120 published studies**

  Reviewed data on each of the landscape elements for (1) biophysical benefits, (2) economic values, (3) beneficiaries (4) costs of implementation

- **Technical and economic analysis of landscape elements**
  - Range of the likely biophysical benefits and economic costs and benefits
  - Estimated performance

Landscape element	References
Trees	Loughner et al. 2012, Shashua-Bar et al. 2009, Davis et al. 2016, and Wang & Akbari 2016, Nowak et al. 2013, Nowak & Dywer 2007, Davies et al. 2011, Nowak et al. 2016, iTree Design v 6.0, Mullaney et al. 2015, Livesley et al. 2014, Sanders 1986, Ikin et al. 2012, Strohbach et al. 2013, Belaire et al. 2014, Gomez-Baggethun et al. 2013, Kuo & Sullivan 2001, Tarran 2009, Interagency Working Group 2016, American Forests 2002, Wolf 2007, Martin Maggio and Appel 1989, Donovan and Butry 2011, Wolf 2015
Green roofs	Alexandri & Jones 2008, Susca et al. 2011, Santamouris 2014, Meek et al. 2014, Getter et al. 2009, Whittinghill et al. 2014, Yang et al. 2008, Currie et al. 2008, Carter et al. 2007, Simmons et al. 2013, Glass 2007, Berndtsson et al. 2010, Harper et al. 2015, Morgan et al. 2013, Rowe et al. 2011, Ahiablame et al. 2012, Colla et al. 2009, Tonietto et al. 2011, Madre et al. 2013, Braaker et al. 2014, Van Renterghem & Botteldooren 2009, Oberndorfer 2007, EPA 2000, Blackhurst et al. 2010, Interagency Working Group 2016, American Forests 2002, Wolf 2015, GSA 2011
Rain gardens	Perring et al. 2016, Davis et al. 2016, Bouchard et al. 2013, Davies et al. 2011, Perring et al. 2013, DeBusk & Wynn 2011, Li et al. 2009, Brown et al. 2013, Jennings 2016, Geosyntec 2016, Glick et al. 2016, Hunt et al. 2008, International BMP Database 2014, Richter et al. 2015, Limouzin et al. 2011, Kazemi et al. 2009, Kazemi et al. 2011, Walsh et al. 2015, Sandifer et al. 2015, Hamel et al. 2013, Interagency Working Group 2016, Wolf 2015, American Forests 2002
Vegetated walls	Alexandri & Jones 2008, Mazzali et al. 2013, Perez et al. 2011, Cameron et al. 2014, Chen et al. 2013, Davies et al. 2011, Currie et al. 2008, Pugh et al. 2012, Madre et al. 2015, Chiquet et al. 2013, Azkorra et al. 2015, Perini 2013, Hassan 2015, Wolf 2015, Nowak et al. 2016, Interagency Working Group 2016, Wolf 2015, American Forests 2002
Porous pavements	Santamouris 2013, Qin 2015, Kevern et al. 2009, Stempihar et al. 2013, Collins et al. 2008, Dreelin et al. 2006, Hunt et al. 2008, Ball and Rankin 2010, Geosyntec 2016, International Stormwater BMP Database 2014, Richter et al. 2015, Ahiablame et al. 2012, Bean et al. 2007, American Forests 2002, Century West Engineering (no date)
Cisterns	Geosyntec 2016, Glick et al. 2016, Walsh et al. 2015, American Forests 2002

Functional Green Development Process

Research provided a **rating for each landscape element based on its ecological and economic performance**. The ratings indicate the performance of each landscape **element relative to the others**.

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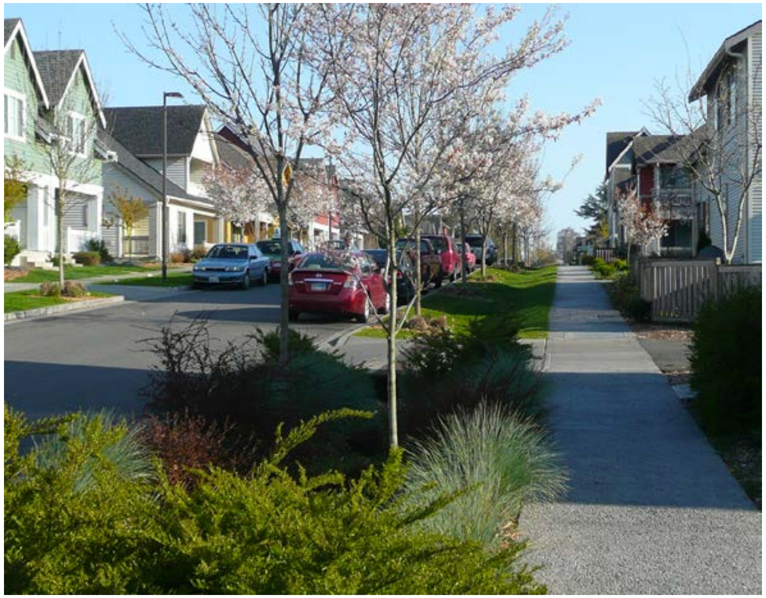


Functional Green Development Process

Multi-Criteria Decision Analysis - allowed us to summarize across the 9 criteria we evaluated – including ecosystem services and economic considerations – and arrive at one value that represents performance across all 9 criteria.

Landscape elements	Scenario 1 Rating	Scenario 2 Rating	Scenario 3 Rating	Scenario 4 Rating	AVERAGE RATING
Existing tree	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
Newly planted tree	★★★	★★★	★★★★	★★★	★★★
Green roof	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
Rain garden	★★★★	★★★	★★★★	★★★★	★★★★
Vegetated wall	★★	★★	★★★	★★	★★
Planting beds	★	★	★★	★	★
Porous pavement	★	★	★	★	★
Cistern	★	★	★	★	★

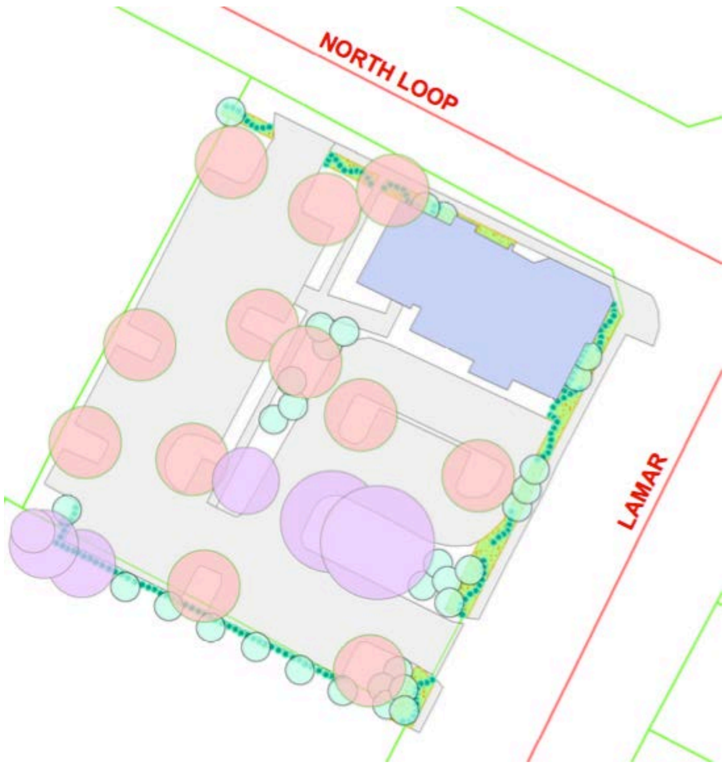
*Bonus points: All rated equally – one star

Functional Green multiplier for each landscape element is based on its ecological and economic performance. The multiplier indicates the performance of each **landscape element relative to the others**.

Landscape elements	Multiplier
Vegetation	
Existing trees	**0.8**
Newly planted trees	**0.4-0.6**
Shrubs, ornamental grasses and large perennials	**0.3**
Ground cover	**0.2**
Turf grass	**0.1**
Specialized media	
Green roof media - extensive	**0.5**
Green roof media - intensive	**0.6**
Rain garden media	**0.3**
Additional elements	
Porous pavement	**0.4**
Vegetated walls	**0.5**
Cistern	**0.3**
Bonus options	
bonus: native or adapted drought tolerant vegetation	**0.1**
bonus: alternative water irrigation	**0.1**
bonus: pollinator resources	**0.1**
bonus: enhanced soil systems	**0.1**

Functional Green Development Process

Test **landscape elements multiplier** and parcel **target score** based on **City of Austin standard landscape code** case studies and **other projects over 81% impervious cover**



Landscape	Project	Address	Size acres	IC
Standard Landscape Code	Balcones Ranch Apartments	13145 N US 183 HIGHWAY, 78729	12.17 ac/53,292 sf	55% existing, 70% allowed
Standard Landscape Code	Villas of 55th	502 W 55th Street 78751	0.28 ac	59%, 65% allowed
Standard Landscape Code	Glazer's Distributors Expansion	8119 Exchange Drive, 78754	13.5 ac	72%, 80% allowed
Standard Landscape Code	Taco Cabana	5242 N LAMAR BOULEVARD, 78756	0.87 ac	72%, 95% allowed
Standard Landscape Code	The Groves at Lamar	3607 South Lamar Boulevard	2.3 acres	77%
As designed	Highland Greystar	Highland mall	3.2	83%
As built	Rainey		1.6	86%
As built	AMLI	5350 Burnet	2.4	87%
As built	San Gabriel	South lamar	0.33 ac	90%
As built	SC Hotel	1603 S Congress Ave	0.95 ac	95%
As built	5th & Colorado	downtown	0.7	100%
As built	Seven Rio	615 W 7th St, Austin, TX 78701	0.8	100%

Balcones Ranch Apartments (1)

13145 N US 183 HIGHWAY

Size: 12.17 acres
IC: 55%
Score: 0.23
Standard Landscape Code

Landscape elements:
Existing trees (88,083)
Newly planted trees (56,549)
Shrubs (9686)
Groundcover (11,230)
Turf (50,060)
Rain garden (25,305)
Cistern (7,842)
Native plants (88,083)

Assumptions:
1. Detention pond counted as rain garden
2. Sand filter counted as cistern
3. Turf in medians and rain garden

Balcones Ranch Apartments (2)
13145 N US 183 HIGHWAY

Size: 12.17 acres
IC: 55%
Score: 0.22
Standard Landscape Code

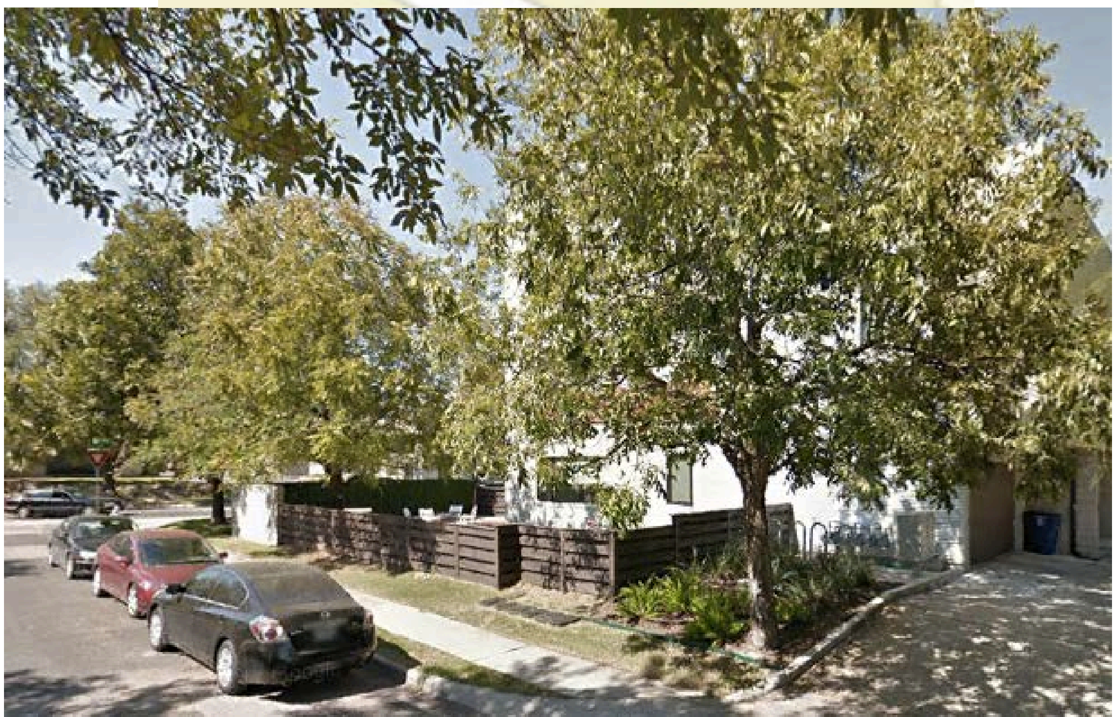
Landscape elements:
Existing trees (88,083)
Newly planted trees (56,549)
Shrubs (9686)
Groundcover (11,230)
Turf (50,060)
Native plants (88,083)

Assumptions
1. **Stormwater treated in detention pond and sand filter.**
2. **Detention pond, median and peninsulas covered with turf**

Villas of 55th
502 w 55th Street

Size: 0.28
IC: 59%
Score: 0.44
Standard landscape code

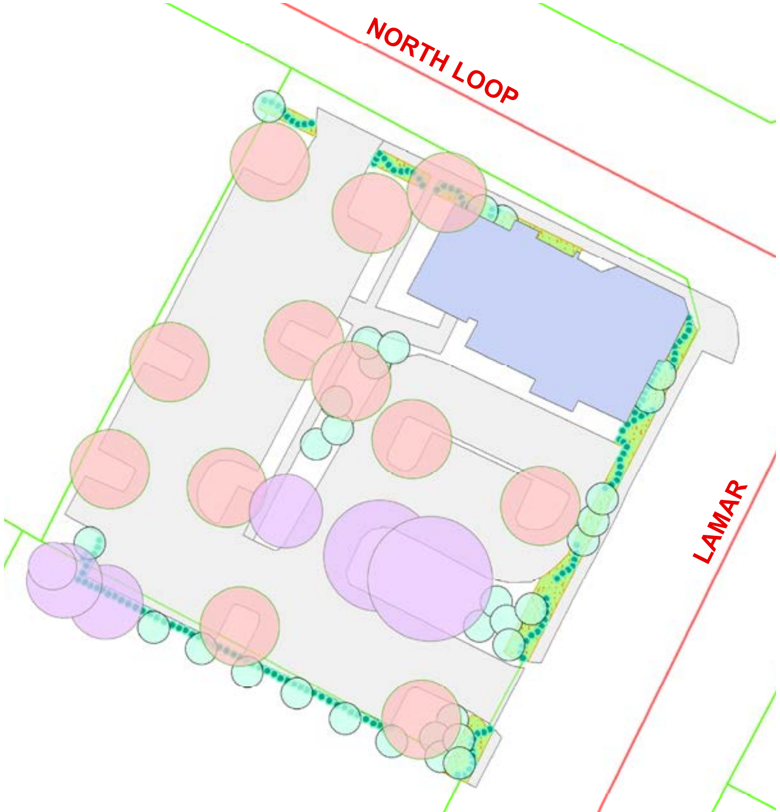
Landscape elements
Existing trees (1,257)
Planted trees (7,775)
Shrubs (813)
Groundcover (417)
Turf (5,424)
Native plants (1,257)

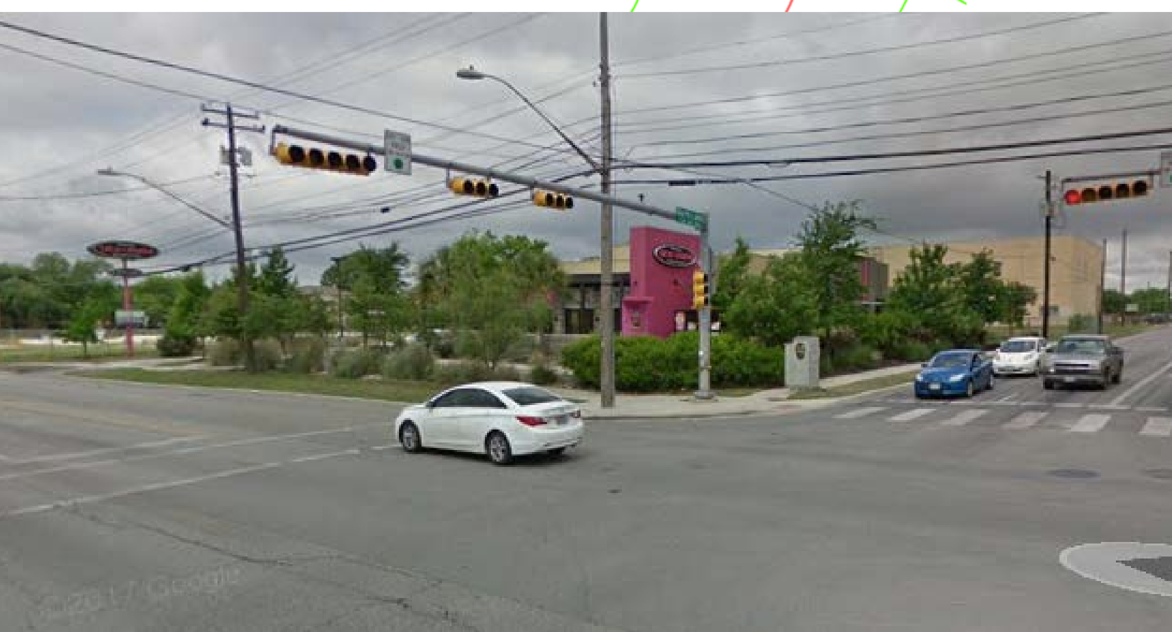


Villas of 55^{th}
502 w 55^{th} Street

Size: 0.28
IC: 59%
Score: 0.44
Standard landscape code

Landscape elements
Existing trees (1,257)
Planted trees (7,775)
Shrubs (813)
Groundcover (417)
Turf (5,424)
Native plants (1,257)

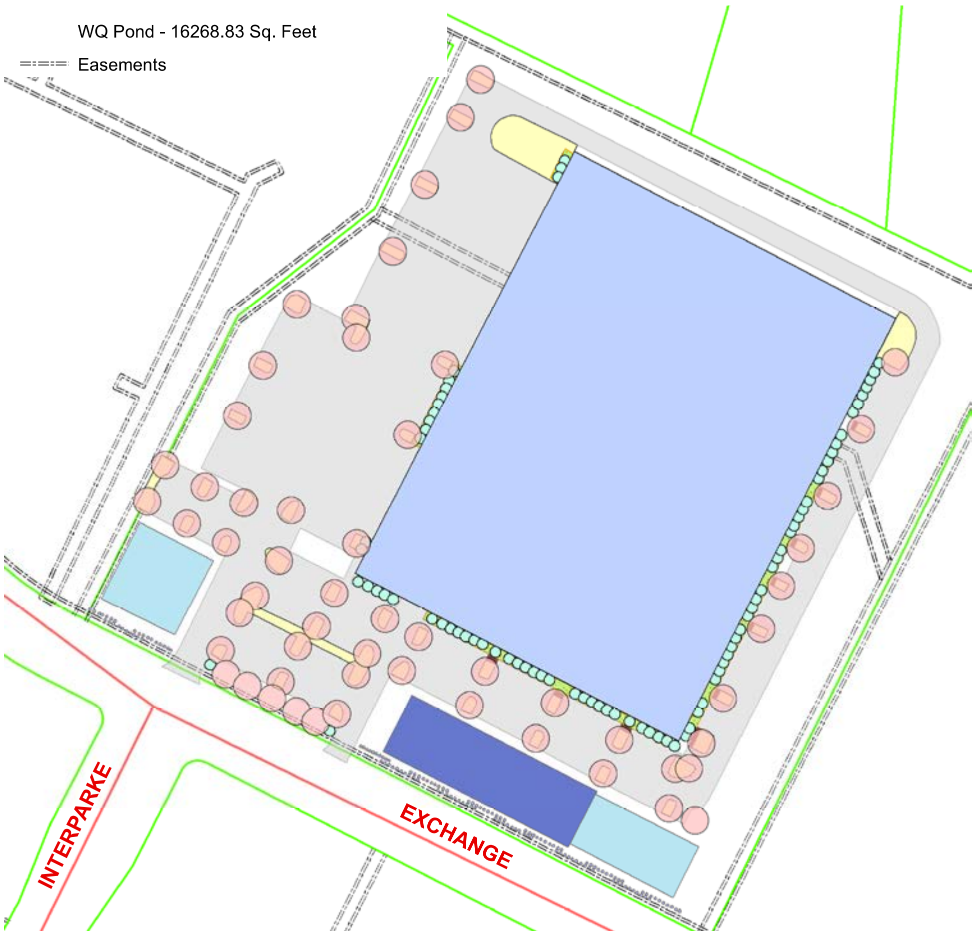




Taco Cabana
5242 N LAMAR BOULEVARD

Size: 0.87 acre
IC: 72%
Score: 0.34
Standard Landscape Code

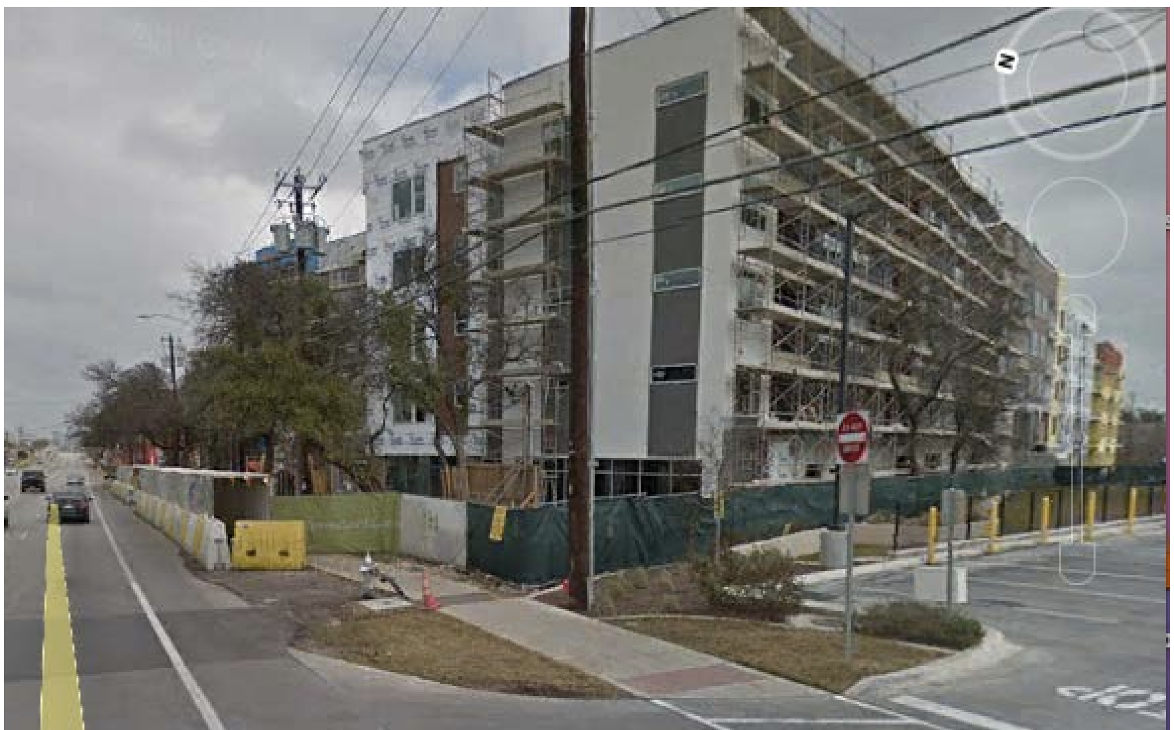
Landscape elements
Existing trees (5,281)
Planted trees (16,258)
Shrubs (1,059)
Groundcover (1,934)
Native plants (5,281)



Glazer's Distribution
8119 Exchange Drive

Size: 13.5 acres
IC: 72%
Score: 0.06
Standard Landscape Code

Landscape elements
Newly planted trees (53,721)
Shrubs (8,909)
Groundcover (7,920)
Rain garden (7,700)
Turf (58,834)
Native plants (53,721)

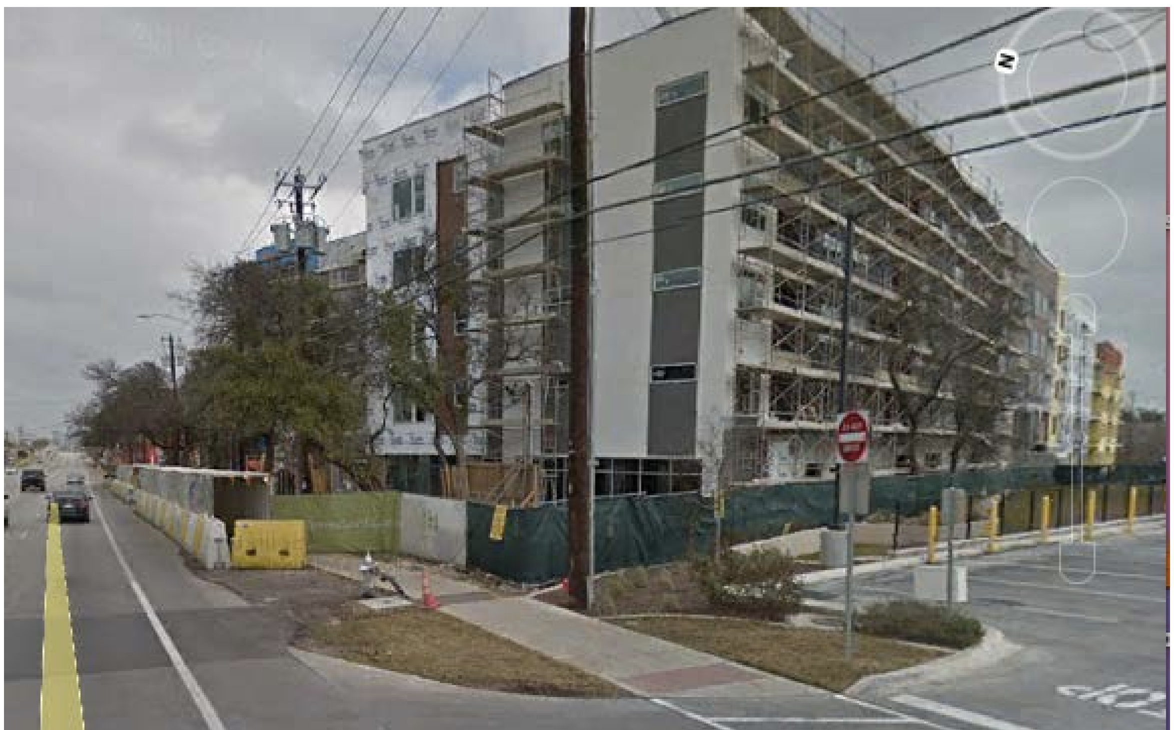


The Groves at Lamar (1)
3607 South Lamar Boulevard

Size: 2.3 acres
IC: 77%
Score: 0.29
Standard landscape code

Landscape elements
Existing trees (12,566)
Planted trees (31,671)
Shrubs (1,650)
Groundcover (512)
Turf (10,770)
Cistern (12,555)
Native plants (8,792)

Assumptions:
15’ easement
Compatibility buffer
Reduced building footprint



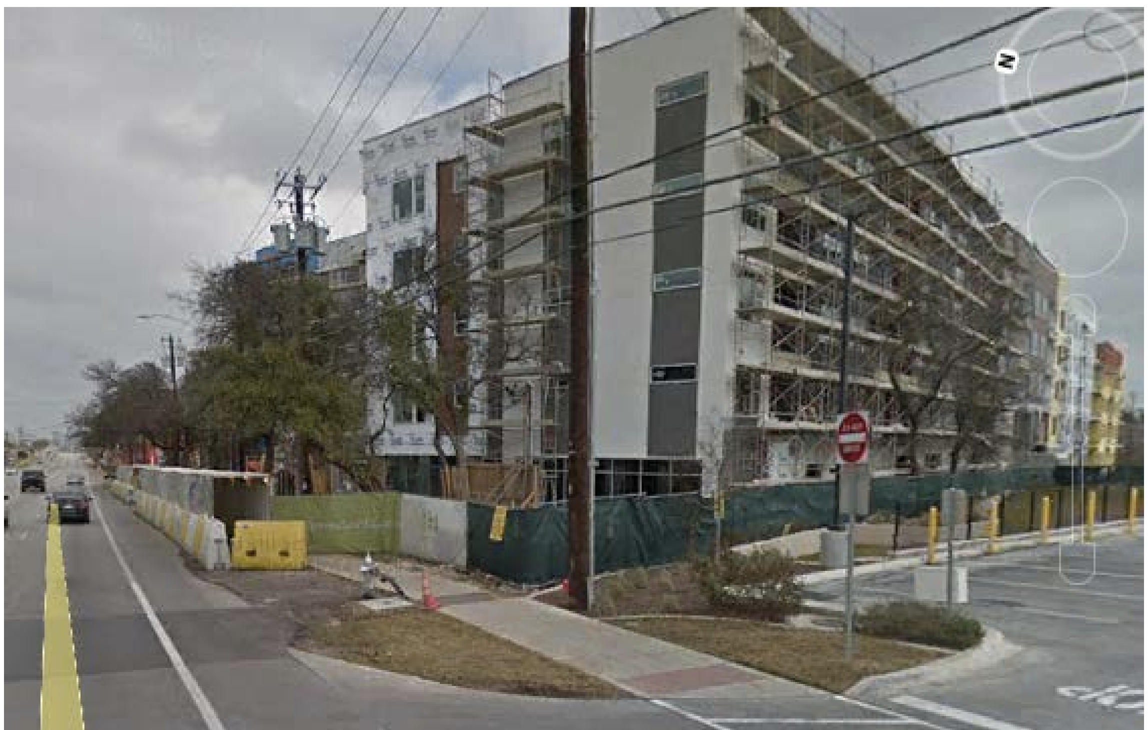
The Groves at Lamar (2)

3607 South Lamar Boulevard

Size: 2.3 acres
IC: 77%
Score: 0.26
Standard landscape code

Landscape elements
Existing trees (8,796)
Planted trees (31,318)
Shrubs (1,395)
Groundcover (256)
Turf (10,770)
Cistern (12,555)
Native plants (8,792)

Assumptions:
Without 15' easement
Compatibility buffer
Reduced building footprint

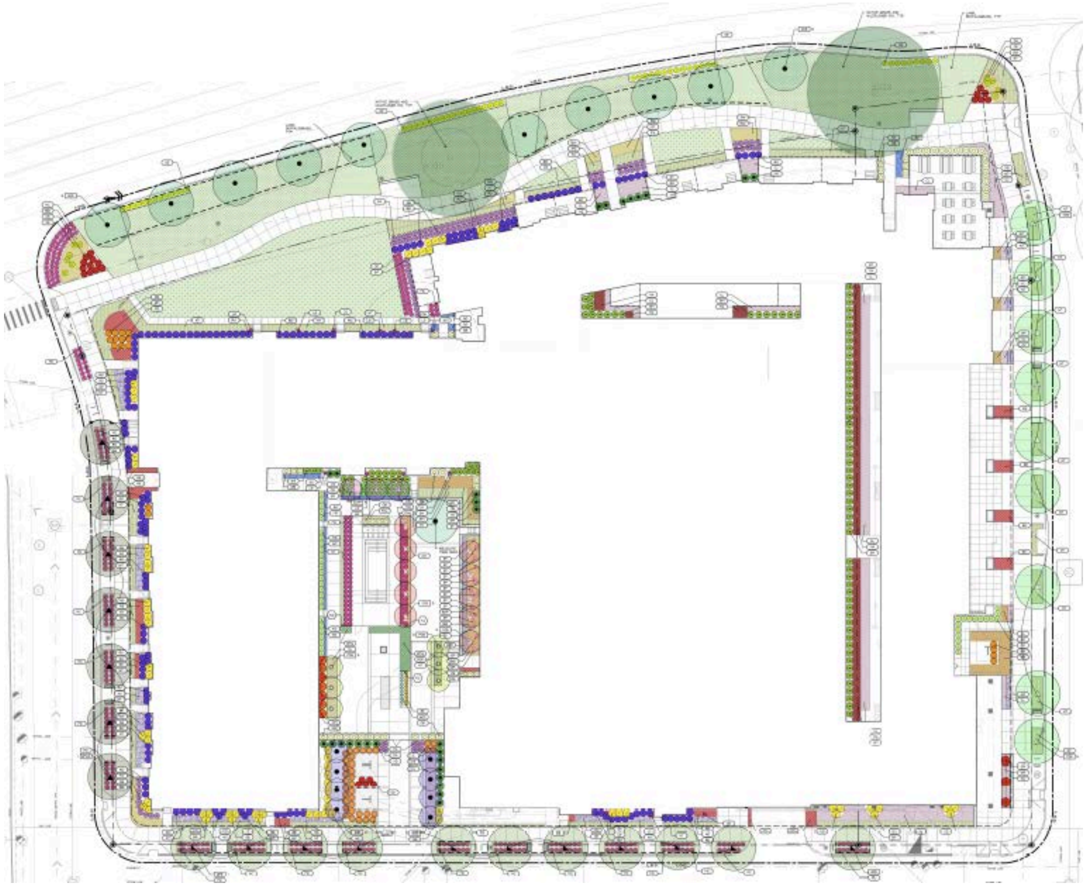


The Groves at Lamar (3)
3607 South Lamar Boulevard

Size: 2.3 acres
IC: 77%
Score: 0.13
Standard landscape code

Landscape elements
Existing trees (12,566)
Planted trees (353)
Shrubs (512)
Groundcover (512)
Turf (512)
Cistern (12,555)
Native plants (12,560)

Assumptions:
15’ easement
No compatibility buffer
Building footprint as is



Highland Greystar
Highland Mall Redevelopment

Size: 3.23
IC: 83%
Score: 0.30
Existing landscape (planned)

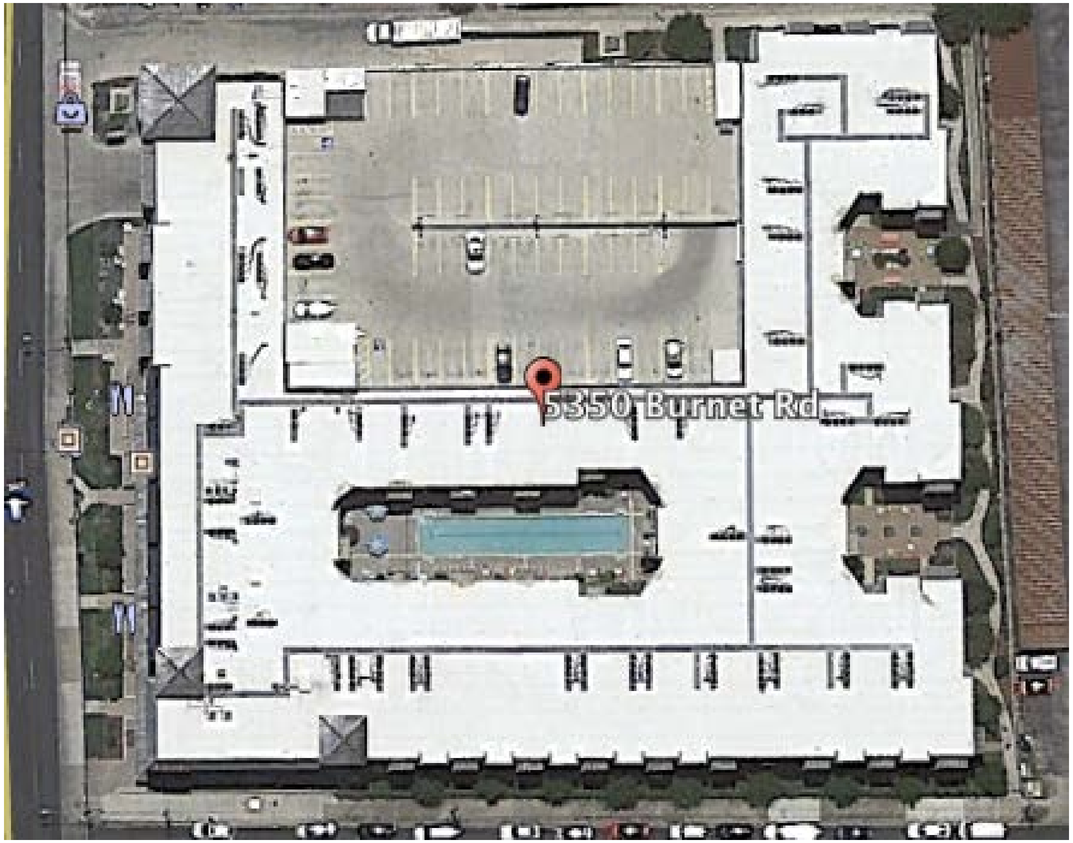
Landscape elements
Existing trees (2,513)
Planted trees (42,804)
Shrubs (7,408)
Turf (13,270)
Native plants (45,317)

Note: stormwater is handled off site in a regional detention pond making this similar to payment in lieu case studies

Rainey
Rainey Street

Size: 1.6 acres
IC: 86%
Score: 0.28
Existing landscape

Landscape elements
Existing trees (2,513)
Planted trees (23,287)
Shrubs (1,108)
Groundcover (4,167)
Native plants (20,106)



AMLI
5350 Burnet

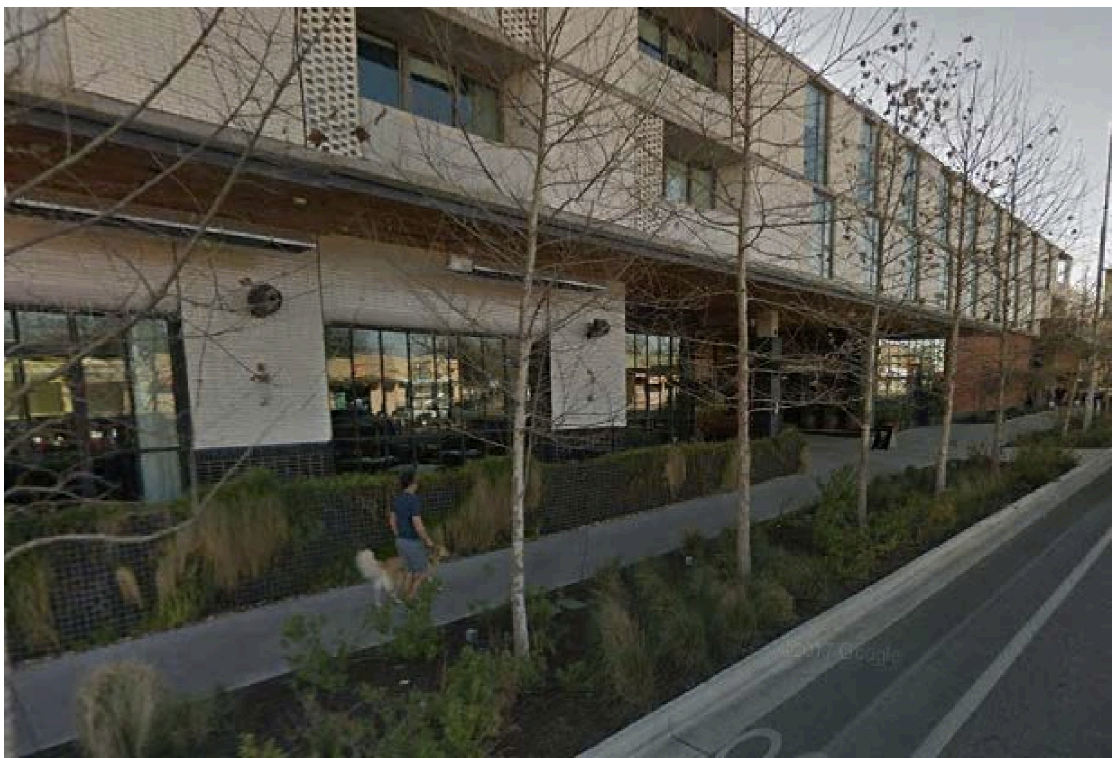
Size: 2.4 acres
IC: 87%
Score: 0.13
Existing landscape

Landscape elements
Planted trees (18,476)
Shrubs (2,600)
Groundcover (2,000)
Turf (2,000)
Rain garden (1000)
Native plants (18,476)

San Gabriel
San Gabriel & 25th

Size: 0.33 acre
IC: 90%
Score: 0.22
Existing landscape

Landscape elements
Planted trees (4,948)
Shrubs (261)
Ground cover (261)
Native plants (4,948)



South Congress Hotel

1603 S Congress Ave.

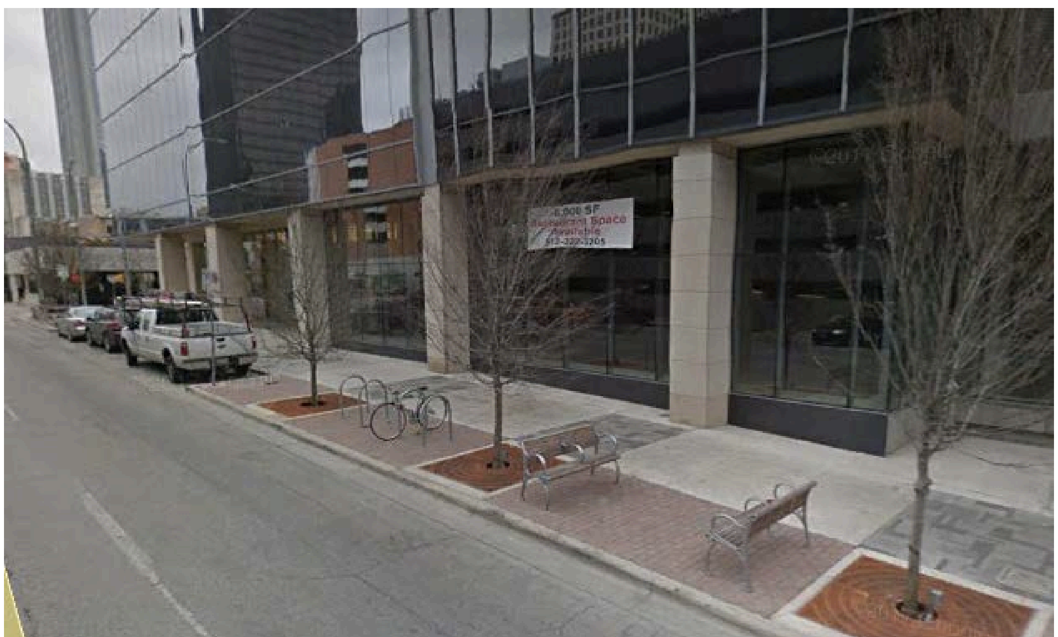
Size: 0.95 acre
IC: 95%
Score: 0.33
Existing landscape

Landscape elements
Planted trees (19,792)
Green wall (2,343)
Shrubs (4,991)
Groundcover (539)
Native plants (9,879)

South Congress Hotel
1603 S Congress Ave.

Size: 0.95 acre
IC: 95%
Score: 0.33
Existing landscape

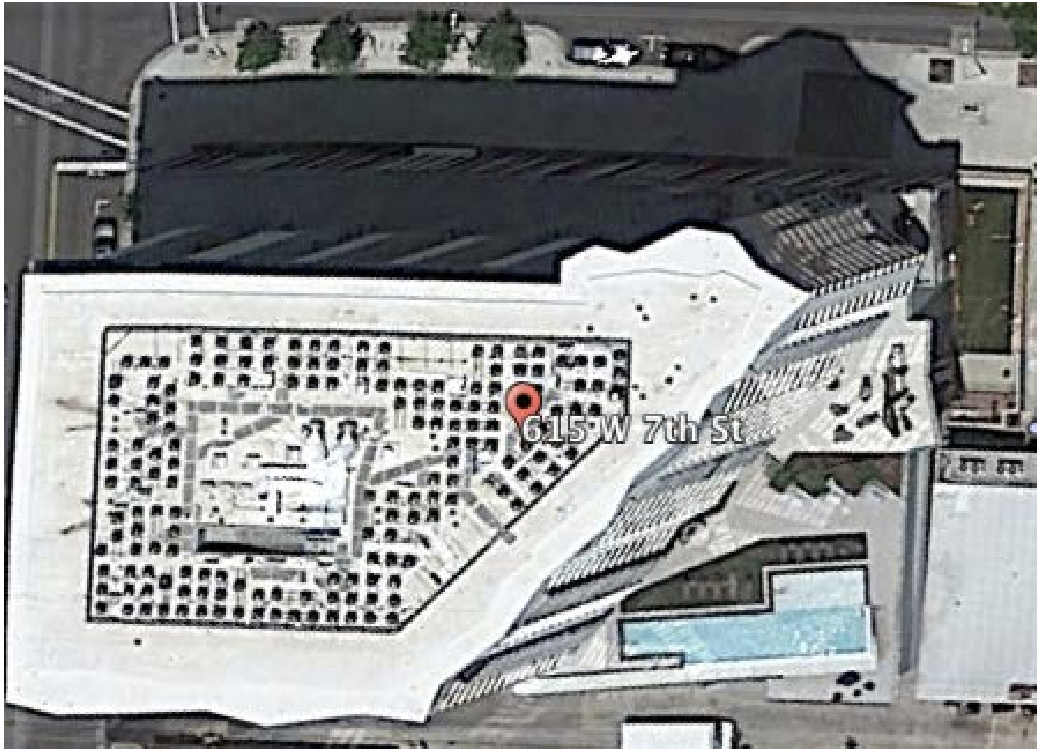
Landscape elements
Planted trees (19,792)
Green wall (2,343)
Shrubs (4,991)
Groundcover (539)
Native plants (9,879)

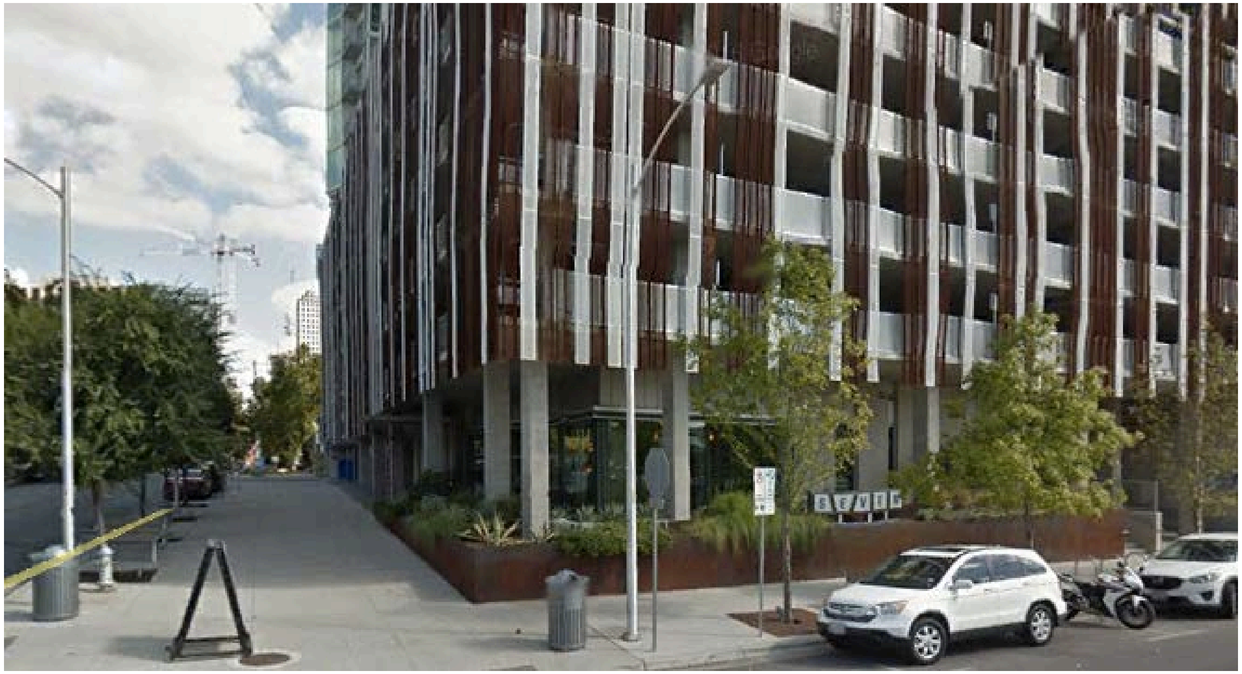


5^{th} & Colorado
Downtown

Size: 0.66
IC: 100%
Score: 0.16
Existing landscape

Landscape elements
Planted trees (6,362)
Native plants (6,362)





Seven Rio
615 W 7th Street

Size: 0.75 acre
IC: 100%
Score: 0.18
Existing landscape

Landscape elements
Planted trees (5,655)
Shrubs (820)
Groundcover (820)
Native plants (5,662)

Landscape	Project	Address	Size acres	IC	Score
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Standard Landscape Code	Glazer's Distributors Expansion	8119 Exchange Drive, 78754	13.5 ac	72%, 80% allowed	0.06
Standard Landscape Code	Taco Cabana	5242 N LAMAR BOULEVARD, 78756	0.87 ac	72%, 95% allowed	0.34
Standard Landscape Code	The Groves at Lamar	3607 South Lamar Boulevard	2.3 acres	77%	0.13 - 0.29
As designed	Highland Greystar	Highland mall	3.2	83%	0.25
As built	Rainey		1.6	86%	0.28
As built	AMLI	5350 Burnet	2.4	87%	0.13
As built	San Gabriel	South lamar	0.33 ac	90%	0.22
As built	SC Hotel	1603 S Congress Ave	0.95 ac	95%	0.33
As built	5th & Colorado	downtown	0.7	100%	0.13
As built	Seven Rio	615 W 7th St, Austin, TX 78701	0.8	100%	0.12

Functional Green Next Steps

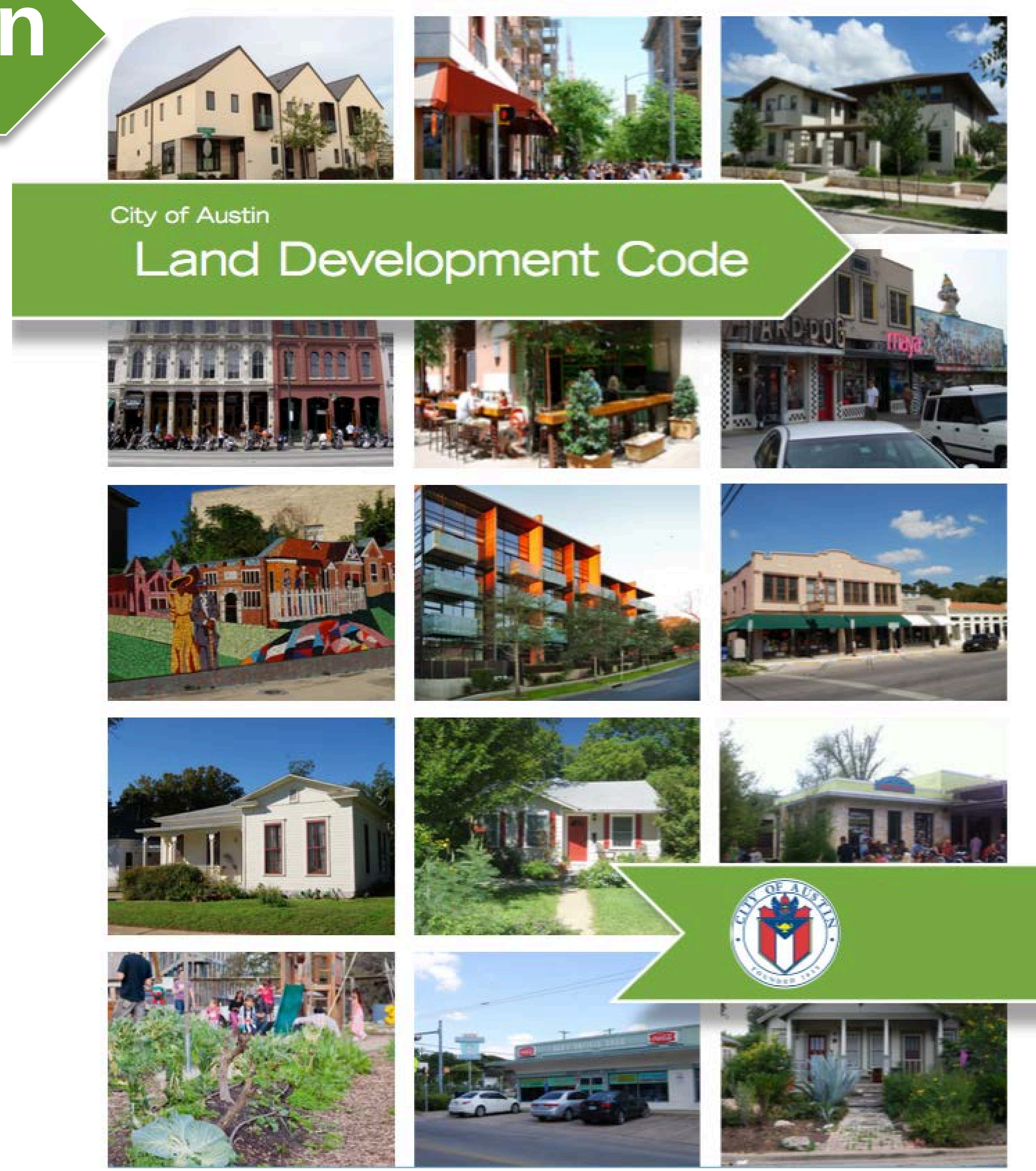
- Follow up meeting to discuss feedback 12/13 or 12/14
- Functional Green development cost for various building types
- Meet with COA Landscape and Watershed staff to discuss economic findings and preliminary proof of concept studies
- Proof of concept studies – continue to test landscape element weights and target score
- Meet with COA Landscape and Watershed staff to provide update and discuss draft materials for February release of draft
- 2/5/17 – Send Functional Green materials to printer

Questions for staff to address prior to next meeting

- Preliminary thoughts about a target score
- Review definitions, measurements and code requirements (excel file)
- Address questions in excel file
- Compile staff comments/questions and send to consultants in advance

Landscape elements	Multiplier	Definition	Measurement	Understanding of code requirements and applications	COA Questions/Comments
Vegetation					
Existing trees	**0.8**	Any tree existing on-site prior to construction of the project under review. In order to receive credit, existing trees must be protected during construction as per COA requirements. Invasive tree species as identified by the COA can not be counted towards existing vegetation credits.	Credit is given for the square foot area of the tree canopy. See COA ECM Appendix F - Descriptive Categories of Tree Species - Mature Width. To determine the area a project may claim per tree, locate tree species in Appendix F and reference the mature width. Count tree in the appopriate Functional Green category. Additional square foot area can be claimed if a project can verify that the existing canopy is larger than shown in Appendix F.	Tree preservation will follow same rules for FG as for all sites: no penalty for removing invasives; preservation = 1. a minimum of 50% of the critical root zone must be preserved at natural grade, with natural ground cover; 2. cut or fill is limited to 4 inches from the 1/2 critical root zone to the 1/4 critical root zone; and 3. no cut or fill is permitted within the 1/4 critical root zone. 4. removal of more than 25% of the canopy constitutes tree removal	
Newly planted trees					
Large trees	**0.6**	Newly planted tree with a mature width of 40 feet or greater. See COA ECM Appendix F - Descriptive Categories of Tree Species - Mature Width.	Credit is given for the square foot area of the tree canopy. See COA ECM Appendix F - Descriptive Categories of Tree Species - Mature Width. To determine the area a project may claim per tree, locate tree species in Appendix F and reference the mature width. Count tree in the appopriate Functional	All streets will be required to have street trees. In all commercial non-transect zones and Core Transit Corridors street trees will be required in the planting zone at an average spacing not greater than 30' o.c. Director shall adopt a list of acceptable trees. Tree list can be found in the ECM Appendix F https://library.municode.com/TX/Austin/codes/environmental_criteria_manual	
Medium trees	**0.5**	Newly planted tree with a mature width between 20 - 39 feet. See COA ECM Appendix F - Descriptive Categories of Tree Species - Mature Width.	Credit is given for the square foot area of the tree canopy. See COA ECM Appendix F - Descriptive Categories of Tree Species - Mature Width. To determine the area a project may claim per tree, locate tree species in Appendix F and reference the mature width. Count tree in the appopriate Functional	All streets will be required to have street trees. In all commercial non-transect zones and Core Transit Corridors street trees will be required in the planting zone at an average spacing not greater than 30' o.c. Director shall adopt a list of acceptable trees. Tree list can be found in the ECM Appendix F https://library.municode.com/TX/Austin/codes/environmental_criteria_manual	
Ornamental trees	**0.4**	Newly planted tree with a mature width between 10 - 19 feet. See COA ECM Appendix F - Descriptive Categories of Tree Species - Mature Width.	Credit is given for the square foot area of the tree canopy. See COA ECM Appendix F - Descriptive Categories of Tree Species - Mature Width. To determine the area a project may claim per tree, locate tree species in Appendix F and reference the mature width. Count tree in the appopriate Functional	All streets will be required to have street trees. In all commercial non-transect zones and Core Transit Corridors street trees will be required in the planting zone at an average spacing not greater than 30' o.c. Director shall adopt a list of acceptable trees. Tree list can be found in the ECM Appendix F https://library.municode.com/TX/Austin/codes/environmental_criteria_manual	
Shrubs, ornamental grasses and large perennials	**0.3**	Shrubs are woody vegetation over 2 feet in height. To achieve credit for ornamental grasses and perennials in FG, plants must have a mature height of at least 2 feet and be evergreen or have year round structure. Perennials not meeting this description will count towards ground cover.	Credit is given for the square foot area of shrub, ornamental grass or large perennial.		
Ground cover	**0.2**	Low spreading vegetation typically less than 24 inches in height.	Credit is given for the square foot area of groundcover.		
Turf grass	**0.1**	turf grass grown from seed or sod	Credit is given for the square foot area of turf.		

Functional Green



Functional Green Development Process

- **Intensive literature review**
  - We summarized **peer-reviewed literature and local reports for the Austin area whenever possible**; we also included **additional studies conducted in locations with climates similar to Austin's (humid subtropical)** when they were available. In cases where little published research exists, we relied on best available data regardless of location or climate.
  - We reviewed **studies of performance for individual landscape elements in the field and lab as well as modeling studies.**

- **Findings were summarized to to provide an estimate of the range of likely benefits.**
  - Results are **summarized on a per-unit or per-area basis**, and where modeling studies are available results are reported for implementation at broader spatial scales. **Identified and reported common metrics** wherever possible to allow comparison.

ECONorthwest
ECONOMICS • FINANCE • PLANNING

DATE: January 12, 2017
TO: Austin City Staff
FROM: Heather Venhaus, Regenerative Environmental Design
Amy Belaire, PhD
Ed MacMullan and Sarah Reich, ECONorthwest
SUBJECT: Results of Task 7B—Landscape Elements and Ecosystem Services Literature Review

1 Introduction

Ecosystem services have become a mainstream concept to describe how natural resources and processes interact with and benefit human society. In 2005, the Millennium Ecosystem Assessment (MA), a pivotal work involving over 1,300 scientists, formalized a definition and classification of ecosystem services that is still widely recognized and used. The MA defined ecosystem services concisely as, “the benefits people obtain from ecosystems” (MA 2005, page v). In 2015, the US EPA developed the “National Ecosystem Services Classification System” (NESCS). NESCS provides a framework to help identify and describe the human welfare impacts of changes in the supply of ecosystem services. (US EPA, 2015)

Our analysis focuses on the ecosystem services and their associated economic values of a range of landscape elements that could be incorporated in urban sites. These alternatives include: planting street trees; installing green roofs; planting rain gardens and other bioretention structures; installing green façades on buildings; substituting porous pavement for asphalt or cement roadways; and collecting rainwater via cisterns or similar catchment systems. These landscape elements, collectively known by a variety of names including “low impact development,” and “green infrastructure,” provide ecosystem services important to municipalities, property owners and residents in urban areas. They provide the following ecosystem services that are particularly relevant in urban landscapes and have been prioritized by the City of Austin:

- Reducing stormwater volumes by infiltrating it into the ground or releasing it over time into a city’s stormwater pipes and other “grey” stormwater infrastructure.
- Filtering stormwater onsite and improving downstream water quality.
- Reducing downstream flooding.
- Improving air quality with vegetation that sequesters carbon, removes particulate matter, and captures other air-borne contaminants.
- Moderating air temperatures and mitigating urban heat island effects.
- Providing habitat value and resources for biodiversity.
- Providing visual amenities.

Economists value these benefits a number of ways. The *avoided-cost* method estimates benefit values based on the amount and cost of municipal services avoided because of the landscape elements in place. An example is the volume of stormwater kept out of a jurisdiction's system of stormwater pipes and treatment facilities, and the associated cost savings of not having to process this volume of stormwater. *Hedonic analyses* estimate the impacts of landscape components on nearby property values. These analyses control for property-specific attributes, e.g., number of bedrooms, size of lot, school district, etc. and estimate the resulting impact on property values from landscape components, e.g., street trees. *Contingent valuation* studies estimate people's willingness to pay to protect landscape attributes. For example, this type of study could estimate the value that residents place on the habitat benefits provided by a city's green roofs.

The state of the science of ecosystem services is such that the available data are typically insufficient to allow quantifying and valuing all ecosystem services from all green infrastructure applications. While the body of relevant literature and data continues growing, much work remains to fill quantification and valuation gaps. Another point to consider is that the supply of ecosystem services and their associated economic values from green infrastructure can be very site specific. That is, local soils, landscape and climate conditions influence the supply of ecosystem services. These conditions, plus local cost of services, property values, etc., can influence ecosystem service values. For this reason, care must be taken when considering using supply and value estimates from past studies conducted elsewhere.

The purpose of this literature review is to summarize estimates of the supply and value of ecosystem services provided by six key landscape elements expected to be included in the City of Austin's Functional Green program. This review focuses on the relationship between the landscape elements and the magnitude and quality of ecosystem goods and services that flow from the landscape. For each of the landscape elements, we review relevant ecosystem services literature from four perspectives: (1) biophysical benefits, (2) economic values, (3) beneficiaries, and (4) costs of implementation. Whenever possible, we refer to studies conducted in the Austin area or in locations with similar climate conditions (humid subtropical climate zones as classified by Koppen Climate Classification System). In cases where Austin-specific data are not available, we report results from studies conducted elsewhere. In some cases, the available data do not allow quantification or valuation of an ecosystem service, so we describe supply and value qualitatively.

2 Trees

2.1 Biophysical Benefits

Extensive research has been conducted on the environmental and social benefits of trees in urban landscapes. In Austin, Texas, a comprehensive study of over 200 field plots provided input data for the U.S. Forest Service's iTree Eco modeling software in 2014 (Nowak et al. 2016). The field data collection and modeling effort allowed for a range of ecosystem services to be quantified in biophysical and economic terms for Austin's trees. Trees within developed land uses account for approximately 40 percent of Austin's urban forest, suggesting that the benefits of trees can be integrated throughout the urban mosaic and provide extensive benefits to citizens across the city.

More broadly, previous research in urban landscapes indicates that urban trees are the most powerful generators of ecosystem services within highly developed environments as key providers of regulating, supporting, provisioning, and cultural services (Nowak and Dywer 2007, Mullaney et al. 2015). Urban trees provide a broad range of biophysical benefits, including regulating microclimate, capturing air pollutants, sequestering and storing carbon, reducing stormwater runoff, and providing resources for biodiversity. Most of these benefits are correlated with the leaf area of the trees; larger trees and those with greater leaf area provide greater benefits than smaller trees or trees with less leaf area (Nowak et al. 2016). In Austin, trees with particularly high leaf area that may be included in streetscapes include live oaks and cedar elms.

As microclimate regulators, trees provide shade by acting as structural shields from solar radiation (blocking 70 to 90 percent of incoming solar radiation on sunny days, Heisler 1986); they also provide cooling benefits on sunny days through evapotranspiration, which can disperse to provide an overall cooling effect at a broader spatial scale. Research in a humid subtropical climate (Maryland, USA) examined the collective effects of street trees on urban heat island effects and found that tree cover adjacent to urban roads can decrease surface air temperatures by 7° F (4.1K), road-surface temperatures by 27° F, and building wall temperatures by 16° F (Loughner et al. 2012). In Austin, the cooling benefits of trees have been quantified in terms of the projected energy savings that buildings could save on air conditioning costs due to tree location, size, and proximity to building walls and roofs, with a net savings of $18.9 million annually for residential buildings (Nowak et al. 2016). These energy savings also result in substantial avoided greenhouse gas emissions from power plants. The cooling effects of urban trees can also lead to reduced formation of ground-level ozone, an air pollutant linked with serious respiratory health effects (Nowak and Dywer 2007).

Trees also play a direct role in urban air quality, by storing and sequestering carbon, capturing gaseous air pollutants through leaf stomata, and intercepting particles on plant surfaces (Nowak and Dywer 2007). Collectively, Austin's existing tree canopy contributes to the annual removal of 1,120 tons of O_3, 86 tons of NO_2, 24 tons of $PM_{2.5}$, and 23 tons of SO_2 (Nowak et al. 2016). Some trees can emit volatile organic compounds (VOCs), which are precursors to O_3 and CO formation; however, this process is temperature dependent, and the cooling effects of trees are expected to outweigh the effects of VOC emission (Nowak and Dywer 2007). Furthermore, trees take in carbon from the atmosphere as they grow, with one large healthy tree sequestering about 93 kg C per year (Nowak and Dywer 2007). Austin's trees collectively store approximately 1.9 million tons of carbon in their biomass, with an annual net sequestration rate of 67,000 tons of C per year (Nowak et al. 2016). In urban areas, the vast majority of the carbon pool is stored in trees rather than herbaceous plants or smaller woody vegetation (Davies et al. 2011).

Trees also contribute to stormwater management goals in urban areas by intercepting rainwater and promoting infiltration and water storage in soil, which in turn leads to reduced peak flow and runoff volumes. An individual tree is estimated to reduce stormwater runoff volume by 113-400 cubic feet each year (Mullaney et al. 2015). Calculations performed by City of Austin staff suggest that the stormwater management benefits of trees (specifically interception of rainwater) are relatively low compared to the retention benefits of other green infrastructure such as rain gardens. The collective stormwater benefits of trees in Austin was estimated at 65 million cubic feet of "avoided runoff" each year (Nowak et al. 2016).

Trees benefit biodiversity by providing habitat resources and enhancing habitat connectivity across urban landscapes (Strohbach et al. 2013, Ikin et al. 2013, Belaire et al. 2014). Research also demonstrates that trees can contribute to noise reduction in urban areas (reviewed in Gomez-Baggethun and Barton 2013) and a variety of social benefits, including reduced crime (Kuo and Sullivan 2001) and improved road safety for drivers and pedestrians (reviewed in Tarran 2009).

2.2 Economic Benefits

The economic benefits of trees derive from their biophysical effects. For several of these effects, there is a strong body of literature assigning a dollar value to trees, including benefits arising from trees' positive impact on air quality, local climate regulation, carbon uptake, and property values.

2.2.1 Value of Air Pollutant Removal and Emissions Avoidance

Trees reduce air pollution by taking up and filtering pollutants already in the air, and by regulating local climate conditions, which can reduce energy use and associated air pollution. Economists measure the value of air quality improvements in several ways. The iTree Eco Modeling Software described above, and used in the Nowak et al. (2016) study of the value of trees in Austin, uses an approach that quantifies the avoided costs associated with pollutants' effects on human health: as pollutant concentrations decrease, the costs associated with pollution-induced health conditions, such as premature death, respiratory conditions, and absenteeism due to illness also decrease. The iTree model integrates data from U.S. EPA's BenMAP tool, which estimates the health impacts and economic value of changes in air quality. This modeling process accounts for local population density and age characteristics where air quality benefits occur, because the value of diminished air pollution is greater where there are more people to benefit. Also, benefits are greater among older and younger populations, which are typically more vulnerable to air pollution. Table 1 shows the values from iTree for rural and urban areas in Austin, showing the differences in value based on the population differences in different parts of the city.

Table 1. Value of Air Pollutant Removal (Dollars per Pound in 2015 Dollars)

	Values for the City of Austin (Nowak et al. 2016)	Values for a Rural Site in Austin	Values for an Urban Site in Austin[1]
Nitrogen Dioxide (NO_2)	$0.14	$0.06	$0.15
Sulfur Dioxide (SO_2)	$0.04	$0.02	$0.04
Small Particulate Matter	$22.68	$12.00	$29.72

Sources: iTree
Notes: [1] This site is typical of the downtown area where Austin's Functional Green program is focused.

2.2.2 Value of Carbon Emissions Avoidance and Carbon Sequestration

Trees provide benefits for global climate regulation by sequestering carbon and by regulating local climate conditions, which can reduce energy consumption by reducing building heating and cooling demand. The amount of carbon sequestration varies by species and age of the tree. The amount of carbon emissions avoided by reducing energy demand depends on local climate conditions and on the placement of trees relative to buildings.

Trees in Austin store (taking into account decomposition) approximately 67,000 tons of carbon each year, valued at about $8.5 million per year (Nowak et al. 2016, calculated based on reported information for value of gross carbon sequestered each year). Trees also offset energy demand (see below), which reduces carbon emissions from fossil-fuel-based power sources, valued at almost $5 million (Nowak et al. 2016). This equates to about $35 per ton of CO_2 offset or sequestered, which is based on the U.S. Council on Environmental Quality and the EPA's recommendations for valuing the social cost of carbon. The EPA's guidance on valuing carbon sequestration and avoided carbon dioxide emissions recommends using a value between approximately $12 and $65 per metric ton of CO_2 for emissions avoided or carbon dioxide equivalent sequestered in 2015 (Interagency Working Group 2016; dollars converted to 2015 based on the CPI; range depends on the discount rate used to adjust future damages). This value accounts for the social cost of carbon emitted today, accounting for costs of effects associated with that unit of carbon that accrue over time. The value of a metric ton of carbon dioxide equivalent sequestered (or carbon dioxide emissions avoided) in the future (by 2050) increases to between $30 and $110, to account for the cumulative and increasing damages attributable to climate change (Interagency Working Group 2016; dollars converted to 2015 based on the CPI).

2.2.3 Energy Costs

Homes and other buildings with appropriately located trees may cost less to heat and cool. The amount of avoided energy costs depends on the location of the trees relative to the structure, the local climate, and the efficiency of the building itself. Multi-story and multi-family residential buildings experience fewer benefits than single-family residential buildings, because they are less influenced by shade effects of trees and more by climate conditions (McPherson and Simpson 2003). Even in areas dominated by multi-story buildings, a high density of urban trees helps reduce energy demand by reducing the urban heat-island effect, lowering ambient air temperature. Nowak et al. (2016) suggests that interactions between trees and buildings reduces the City of Austin's residents' energy costs by almost $19 million each year. This also reflects the offsetting effect that trees may increase heating demands during the winter, because they (especially evergreen species) provide shade when sun exposure would otherwise offset heating expenses. This offsetting effect is smaller for multi-story buildings, because they are less influenced by the shading effects (McPherson and Simpson 2003).

2.2.4 Property Values

Trees offer many amenities that contribute to property values. A review of studies comparing areas with street trees to areas without across the country found that street trees can add between 2 and 10 percent (potentially up to 15 percent for mature trees in high-income neighborhoods) to property values (Wolf 2007). A mature tree canopy throughout a neighborhood can add between 6 and 9 percent to the homes in the neighborhood. There has been comparatively little research on the influence of trees on the value of multi-family and rental dwellings, but limited research has found that in Portland, Oregon, street trees increase rents (Donovan and Butry 2011). Trees enhance the value of commercial property, by increasing the street appeal to potential consumers and potentially increasing sales, and by increasing rental rates and reducing turnover for commercial offices (Laverne and Winson-Geidman 2003; Wolf 2007). A study of property values in Austin found, using two different methods, that street trees contribute between 13 and 19 percent of the value of residential property (Martin, Maggio, and Appel 1989).

2.2.5 Stormwater Runoff Costs

Trees capture and absorb stormwater, which has the potential to generate several economic benefits. These include lower risk of flooding and associated damage, reduced storm/sewer overflow events and potentially improved water quality, and reduced capacity of stormwater management infrastructure in areas with trees, especially combined with bioretention. These benefits all have the potential to yield avoided costs and economic benefits for property owners and the city's taxpayers. Nowak et al. (2016) calculates that Austin's trees capture 65 million cubic feet of stormwater runoff each year. Putting a dollar value on that reduced runoff city-wide is challenging, but examples from elsewhere suggest trees can provide very large benefits. In Washington, D.C., the existing 46 percent tree canopy reduces the need for stormwater retention structures by 949 million cubic feet, saving the District $4.7 billion every 20 years (American Forests 2002). Using a national average of $2 per cubic foot of storage, Austin's trees would provide approximately $130 million in stormwater retention benefits every 20 years (American Forests 2002).

2.2.6 Other Benefits

In addition to these benefits, the literature describes qualitatively additional economic values associated with trees, including health benefits, and benefits associated with increased biodiversity. A recent article attempted to value urban green spaces at the national level, evaluating studies associated with six social and health conditions that show improvement and reduced treatment costs when correlated with access to green spaces: newborn health, ADHD, school performance, crime, Alzheimer's disease, and cardiovascular health. The potential cost savings associated with improvements in these conditions ranges from $2.7 to $6.7 billion per year (Wolf 2015). Some of these benefits are likely at least partially captured by the valuation methods used for the benefits described above (e.g., property values and avoided costs of air pollution), but the quantified benefits almost certainly underestimate the total economic value generated by trees.

2.3 Beneficiaries

Trees generate public and private benefits. Private property owners with trees enjoy heating and cooling savings, increased property value, and enjoyment of the amenities trees provide. Private property owners adjacent to property with tree canopy may also enjoy these benefits without bearing the cost of the investment. Renters in buildings that benefit from trees may enjoy reduced energy costs, but may also pay higher rents that offset the cost savings. The public may enjoy benefits arising from the environmental effects of trees, including mental and physical health improvements from better air quality and enhanced amenities, moderated temperatures from reduced urban heat island effect, and enjoyment of increased biodiversity.

2.4 Costs of Implementation

The cost of trees includes planting, pruning and maintenance, tree and stump removal at the end of a tree's life, pest and disease control, irrigation, and other costs (e.g., infrastructure opportunity costs, liability costs, litter and waste disposal costs, and for public trees, inspection and administration costs) (McPherson 2006). Regional surveys of tree costs as reported by urban arborists and municipal foresters in the Piedmont (North Carolina to Texas) and Interior West (Texas west) are shown in Table 2. Austin sits on the border of these regions, so likely would experience costs somewhere within this range.

Table 2. Costs of Trees (2015$)

	Piedmont Region[a]	Interior West Region[b]
Planting (One-time)	$587	$97-$457
Pruning (Per tree per year, depending on size and age)	$0.07-$5.50	$4-$515
Removal (Per inch of diameter)	$41-$260	$25-$40
Pest and Disease Control (Per tree per year)	$23	N/A
Irrigation (Per year for first 5 years)	N/A	$1.14-$4.57

Sources: [a] Vargas et. al. 2007; [b] McPherson et al. 2006

3 Green roofs

3.1 Biophysical Benefits

Green roofs cover building rooftops with a vegetated surface and substrate, taking the form of an "intensive" or "extensive" design. Intensive green roofs are often designed with diverse vegetation types, including trees, whereas extensive green roofs are often planted with dense, low-growing vegetation in shallower substrates (Oberndorfer et al. 2007, Ahiablame et al. 2012). Green roofs can be one means of increasing vegetation cover in urban landscapes, compensating for the vegetation that was removed during construction. The biophysical benefits of green roofs center on improved stormwater management, reduced temperatures of buildings and broader urban heat islands, and enhanced habitat resources and connectivity for biodiversity. Aesthetic appeal and functional space for urban residents are also possible, depending on design and characteristics (Oberndorfer et al. 2007).

The stormwater management benefits of green roofs have been explored in a wide variety of climates and contexts. Research indicates that green roofs can retain 20-100 percent of rainfall, but this is highly dependent on the amount of rainfall and the existing water holding capacity of the roof during a given storm (reviewed in Ahiablame et al. 2012). In general, green infrastructure such as green roofs, bioretention, and porous pavements experience saturation and therefore provide little benefit in large storms and flash flood events. Studies in Austin and in locations with similar humid subtropical climates (Cfa) demonstrate that green roofs can retain 44-48 percent of rainfall volume during large (e.g., 3-inch) storms and 86-88 percent during smaller (e.g., <1-inch) storms (Carter et al. 2007, Simmons et al. 2013). One study in Maryland, USA found that per-storm retention rates varied depending on storm size, but 74 percent of the total rainfall volume over 10 months was retained by the green roof (Glass 2007). The effects of green roofs on water quality, however, are less clear, with studies showing mixed results for green roofs in removing nutrients and metals from stormwater (Ahiablame et al. 2012). However, one review suggests that as green roofs get older, their performance improves in terms of reducing pollutant loads (Rowe 2011).

Studies conducted at multiple spatial scales suggest that green roofs can contribute substantially to reducing urban heat island effects by increasing the albedo of existing rooftops and increasing the amount of vegetation that provides shade and cooling benefits of evapotranspiration. A modeling study of cities across the globe, including one city in a humid subtropical climate (Hong Kong), found that the maximum roof surface temperature difference for a green roof (compared to a non-vegetated roof) was 45° F cooler on a hot summer day (Alexandri and Jones 2008). Models also indicate that green roofs can reduce average ambient temperatures by up to 2.7-5.4° F when applied more broadly across an urban landscape (Meek et al. 2014, Santamouris 2014). It is important to note that the green roofs on taller buildings may contribute negligible benefits for mitigating broader urban heat island effects (Santamouris 2014). However, the cooling benefits for underlying buildings can translate to reduced air conditioning needs, leading to energy savings and reduced greenhouse gas emissions at power plants as a result (Rowe 2011).

Additional biophysical benefits provided by green roofs include reduction of noise and air pollution in urban streetscapes (Van Renterghem and Botteldooren 2009, Rowe 2011). Green roofs are capable of removing air pollutants from the atmosphere and acting as a carbon sink, depending on plant characteristics and design (Currie et al. 2008, Pugh et al. 2012, Rowe 2011). In addition, the cooling benefits of green roofs may contribute to reduced formation of ground-level ozone (Rowe 2011).

Research in recent years has demonstrated that green roofs support a surprising diversity of invertebrate species, including native pollinators and specialist species (Colla et al. 2009, Tonietto et al. 2011, Madre et al. 2013). Moreover, green roofs can be important "stepping stones" between urban habitat patches and contribute to functional connectivity for some species (Braaker et al. 2014). Several studies have shown that invertebrates respond to green roof habitat regardless of the broader landscape context, which suggests that even small green roofs in highly urbanized surroundings can provide important habitat value for biodiversity (Madre et al. 2013, Tonietto et al. 2011).

3.2 Economic Benefits

Green roofs provide building owners with private costs savings and increased property values. They also provide a variety of public benefits, some of which are quantifiable and some are not, especially at the scale of an individual green roof. In general, in areas that experience droughts, maintenance costs for vegetation can increase due to additional water requirements and the potential replacement of vegetation.

3.2.1 Building Cost Savings

Green roof experts suggest that the lifespan of a roof can double under a green roof, reducing maintenance costs over conventional roofs and leading to a potential $25 per square foot savings. Additional savings to the building owner may come from incentives or development credits offered by the City. In the City of Austin, Green Roofs qualify for meeting development requirements and may qualify a development for a density bonus in the downtown area (City of Austin 2014).

3.2.2 Energy Costs

The insulating effect of the green roof depends on the characteristics of the building it sits on, and the climate where the building is located. In the absence of specific building data, green roof experts suggest the insulative properties of a green roof provide approximately the equivalent of an inch of conventional insulating materials, which typically cost approximately $3 per square foot. Based on these cost savings in addition to reduced periodic repair costs, the building owner may enjoy a cost savings of $32 per square foot over a conventional roof (Breuning No Date). The relative energy savings benefit is greatest for one- and two-story buildings. Multi-story buildings experience energy efficiency improvements only on the few stories below the green roof: floors greater than four stories below the green roof are not impacted (Blackhurst et al. 2010).

3.2.3 Property Values

Green buildings and green roofs have been shown to increase property values. One analysis showed the real estate effect nationally at $13 per square foot of green roof (GSA 2011). Buildings that have views of a green roof experience increases in value as well. A study in New York City found that apartment rents in buildings with green roofs were about 16 percent higher on average than buildings without green roofs (Ichihara and Cohen 2010). Data from national surveys by the U.S. Green Building Council found that green buildings in general realize 5.7 percent more rent than conventional buildings (GSA 2011).

3.2.4 Stormwater Runoff

Modeling results suggest that most green roofs reduce annual stormwater runoff volume. This reduces the stormwater management costs to the City, and may reduce the need for future conventional stormwater infrastructure investments. An individual green roof may not have a measurable effect on public stormwater investment requirements, however more widespread adoption has been shown to produce substantial public savings. In Washington, D.C., a 10 percent increase in green roof coverage could reduce the infrastructure costs in the District's Long-Term Control Plan (LTCP) by $10 million (Deutsch et al 2005). In Detroit, a 10 percent increase in green roof coverage could reduce the LTCP costs by $114 million (Deutsch et al 2005).

3.2.5 Air Quality

Green roofs also provide public economic benefits by improving air quality. The most commonly measured pollutant reductions are nitrogen-oxides and particulate matter. The GSA (2011) calculated that the economic benefit of reducing these pollutants is negligible to almost $0.60 per square foot of green roof. For an individual green roof, this does not add up to a huge benefit, but at a larger scale, the economic benefits become more meaningful.

3.2.6 Health and Well-Being

The improvements in human health and well-being that arise from access and views of greenspaces apply to greenroofs. A green roof that is within view of office space may improve worker productivity: one study found that workers who have a view of vegetation out their window are almost 3 percent more productive (GSA 2011). College students working in a computer lab with plants were 12 percent more productive, demonstrating faster reaction times and lower stress (Lohr et al. 1996). Benefits in the form of less stress, better mental health, and faster recovery times have also been documented for younger students, health care workers, and patients in hospitals. All of these health and well-being effects have economic implications, though they are not easy to quantify. Lower absenteeism has the potential to save employers millions per year, and the effects of reduced stress may contribute to lower health care costs nationally, and higher quality of life (Wolf 2014).

3.3 Beneficiaries

Building owners enjoy cost savings and increased property value, rental rates, and potentially increased worker productivity after installing a green roof. Renters in a building with a greenroof may experience reduced energy costs, depending on site-specific conditions, but higher rental rates may offset this benefit. The public enjoys reduced stormwater management costs, especially if green roof installation is widespread. The public may also enjoy benefits related to air quality improvement and urban heat island mitigation, and enhanced biodiversity if green roof implementation is widespread in an urban area. These public benefits are more limited with isolated green roof applications.

3.4 Costs of Implementation

Installation costs of an extensive green roof may be between around $10 and $30 per square foot more expensive than conventional roofs (Breuning No Date; GSA 2011; Center for Neighborhood Technology No Date), but typically the extra cost for extensive roofs is on the lower end of this range. Over its lifetime, a greenroof will require maintenance of around $15 per square foot (Breuning No Date): annual maintenance is typically higher than a conventional roof by $0.21 to $0.31 per square foot (GSA 2011). The Center for Neighborhood Technology (No Date) suggests maintenance costs for green roofs range from 2 cents per square foot to around 40 cents. The maintenance cost is influenced by roof design and local climate. Table 3 summarizes the construction and maintenance costs, as compiled by the Center for Neighborhood Technology.

Table 3: Costs for Bioretention and Rain Garden Structures (2016$)

	Construction Costs/Sq. Ft.	Maintenance Costs/Sq. Ft.	Useful Lifespan (Years)	
Low	$8.75	$0.020	Long	50
Medium	$15.75	$0.025	Mid	40
High	$31.80	$0.421	Short	25

Source: (Center for Neighborhood Technology, No date)

4 Bioretention, Biofiltration Systems, and Rain Gardens

4.1 Biophysical Benefits

Bioretention, biofiltration systems, and rain gardens are typically small depressions that retain and treat stormwater runoff with plants and soils. Generally, the terms "bioretention cells" and "rain gardens" describe stormwater management systems that are designed to function similarly to natural landscapes by capturing runoff and promoting infiltration/filtration via vegetated systems planted in a variety of media types (Ahiablame et al. 2012). Bioretention cells and rain gardens may or may not be designed with an underdrain, depending on underlying soil conditions. The City of Austin's definition of a "biofiltration" system requires a two-step process, in which runoff is first directed to a sedimentation basin for pre-treatment and then directed through a cell with a biologically active system of plants rooted in a filter medium (City of Austin 2016, Section C). The majority of research conducted thus far has focused on bioretention systems without pre-treatment sedimentation basins. The biophysical benefits provided by these types of system include reduced urban runoff, improved water quality, microclimate regulation, reduced air pollution and noise, and support for urban biodiversity.

Bioretention systems perform particularly well in reducing runoff volumes and peak flow rates and can capture the entire inflow volume, especially in small events. In general, green infrastructure such as green roofs, bioretention, and porous pavements experience saturation and therefore provide little benefit in large storms and flash flood events. A 7-month field study in a humid subtropical climate (Virginia, USA) documented a cumulative volume reduction of 97 percent during the study period; on a per-storm basis, the median volume reduction was 100 percent, with only 5 of 28 storm events producing outflow (DeBusk and

Wynn 2011). Six bioretention cells monitored in Maryland and North Carolina, USA (both humid subtropical climates) for more than 10 months also performed well, with median runoff volume reduction ranging from 40-99 percent across the six sites (Li et al. 2009). A nationwide modeling study with 3-year continuous simulations for real precipitation patterns demonstrated that individual rain gardens in Texas could reduce total runoff volumes by 65 percent (Jennings 2016).

The reduction in runoff volumes also translates into reduction of peak flow rates, with one study in North Carolina, USA documenting a mean peak flow reduction of 99 percent over a two-year time span (Hunt et al. 2008). Modeling studies demonstrate that when bioretention systems and/or rain gardens are implemented broadly across a watershed, they can cumulatively contribute to increased groundwater recharge, increased stream baseflow rates, and reduced number of erosive events in urban streams, which can in turn lead to improved stream ecological health (Hamel et al. 2013, Glick et al. 2016). The in-stream ecological effects of catchment-scale implementation of green infrastructure have been monitored in an innovative Australian study, although no change in ecological indicators has been observed thus far (Walsh et al. 2015).

The performance of bioretention systems in removing pollutants from urban runoff has also been relatively well documented. A lab study conducted with synthetic and real stormwater in Austin, Texas demonstrated that vegetated systems in biofiltration media removed all nutrients (especially total phosphorus, >80 percent removed), metals (>95 percent removed for copper, lead, and zinc), and total suspended solids (>85 percent removed) (Limouzin et al. 2011). A separate study in Austin, Texas indicated that effluent from biofiltration systems had concentrations of total suspended solids, zinc, and *E. coli* that were significantly lower than those of runoff from undeveloped land in Austin (Richter 2015). In general, these results agree with data reported from other studies, with bioretention systems in a variety of settings showing consistently high removal rates for total suspended solids, some nutrients, and metals (although removal rates are dependent upon design characteristics) (reviewed in Ahiablame et al. 2012). Recent studies have also demonstrated bioretention systems can effectively remove *E. coli* over the long-term (70-97 percent removal, in lab experiments conducted by Zhang et al. 2011).

As with other small vegetated areas in urban landscapes, rain gardens and bioretention systems can also store and sequester carbon, mitigate urban heat island effects, reduce noise pollution, and support urban biodiversity. Even small areas of herbaceous cover can store 0.14 kg carbon per square meter (Davies et al. 2011), which can increase substantially as the system ages (i.e., 3.34 kg carbon per square meter after 21 years; Bouchard et al. 2013). In addition, small vegetated areas contribute to overall cooling effects through transpiration (Perring et al. 2013, Davis et al. 2016) and can reduce noise levels in urban areas (Bolund and Hunhammar 1999). Furthermore, a series of studies in Melbourne, Australia demonstrated that bioretention systems support high biodiversity invertebrate species, with greater species richness in bioretention basins than in nearby urban green spaces (Kazemi et al. 2009, Kazemi et al. 2011).

4.2 Economic Benefits

4.2.1 Stormwater

The City of Austin charges property owners a Drainage Utility Fee (DUF) for managing stormwater. The DUF includes a base rate applied to the square footage of a property's impervious area, modified by an adjustment factor. The median household charge is approximately $12 per month (Pantalion, 2016). Biofiltration controls can help reduce stormwater volumes that flow into the City of Austin's stormwater infrastructure, and help property owners qualify for MDC discounts. Monthly discounts range from $0.22 for a 55-gallon reduction in stormwater volume, up to $8.05 per month for reductions of 3,000 gallons or more. These discounts reflect reduced costs to the City of Austin of managing and treating stormwater (Pantalion, 2016). Bioretention and realted storwmater controls help reduce runoff volumes, which can help reduce stormwater management costs.

4.2.2 Carbon Sequestration and Air quality

Bioretention areas that include significant vegetation, including grasses, shrubs, and trees produce environmental benefits ranging from air quality improvements to carbon sequestration. These benefits would be valued using the economic values and methods described above for trees. Shrubs and grasses and other smaller vegetation has smaller effects on these ecosystem services than do trees, so biofiltration that does not include trees would produce a smaller magnitude of these benefits.

4.3 Beneficiaries

Bioretention structures and rain gardens generate benefits for a range of stakeholders. City of Austin stormwater managers benefit through reduced volumes of stormwater managed and processed. Reducing stormwater volumes can also help reduce demand for stormwater services as the city's population grows, thus extending the capacity of the city's stormwater infrastructure further out into the future. Combined, these benefits can reduce operating costs. Property owners benefit through reduced MDC costs. Property owners also incur the costs of implementing the green infrastructure controls, which we address in the next subsection. Residents of multi-family and other rental properties may or may not benefit from reduced MDC costs, depending on their agreements with property owners regarding utility payments. In cases where property owners, not tenants, pay stormwater utility fees, owners may or may not pass reduced MDC costs on to tenants. To the extent that stormwater controls help reduce flooding, they can also help reduce downstream flood risks, damage and costs. These benefits accrue to downstream property owners and to the City of Austin through reduced emergency management and response costs. The carbon sequestration benefits accrue to society at large.

4.4 Cost of Implementation

Costs of implementing bioretention and rain garden stormwater controls can be very site specific depending on local soil, vegetation, and climate conditions. Tables 4A and 4B summarize the instillation and maintenance and management cost information reported in the literature. The "Low" construction costs apply to smaller scale and self-installed controls. In Table 4A, instillation costs for biofiltration and rain gardens reported as cost per cubic foot of stormwater retention volume. Costs for vegetative filter strip reported per square foot of instillation. O&M costs reports as annual average costs per instillation. Costs in Table 4B report per square foot of instillation.

Table 4A: City of Austin Costs for Bioretention and Rain Garden Structures (2016$)

	Low Cost	Average Cost	High Cost	Annual O&M/Instillation
Biofiltration ($/CF)	$5.14	$11.33	$18.05	$3,000
Rain Garden ($/CF)	$8.21	$24.25	61.79	$1,700
Vegetative Filter Strip ($/SF)	$1.98	$3.11	$4.80	$3,076

Source: City of Austin staff, Personal Communication, January 17, 2017.

Table 4B: Nationwide Range of Costs for Bioretention and Rain Garden Structures (2016$)

	Construction Costs/Sq. Ft.	Maintenance Costs/Sq. Ft.	Useful Lifespan (Years)	
Low	$5.943	$0.380	**Long**	50
Medium	$7.805	$0.488	**Mid**	30
High	$18.522	$0.747	**Short**	25

Source; (Center for Neighborhood Technology, No date)

A subdivision in Austin included four bioretention areas as a substitute for the sedimentation-filtration pond that would have otherwise been required. In addition to providing the ecosystem services benefits and values described above, installing the bioretention structures cost approximately $185,000 less. On a per-lot basis, the bioretention option cost approximately $450, compared to approximately $1,700 for the sedimentation-filtration option. (US EPA, 2005)

5 Green Façade

5.1 Biophysical Benefits

The term "green façade" or "green wall" describes built vertical surfaces that support vegetation. Green façades may be "direct," with vegetation growing directly on a wall itself, or "double-skin," which support plants with engineered structures such as cables and create an insulating layer of air between plants and building (Hunter et al. 2012, Perini et al. 2011). In both cases, the plants are rooted in soil at the ground level or in planter boxes. "Living walls," on the other hand, include encased growing medium within a support structure that is anchored on the building surface (i.e., plants need not be rooted in substrate at the base of the wall) (Perini et al. 2011). The biophysical benefits of green façades center on microclimate regulation, noise reduction, and air pollutant capture.

Vegetation adjacent to building walls can contribute substantially to urban microclimates by screening solar radiation before it reaches the building, increasing albedo (reflective capacity), and cooling the surrounding air as plants transpire (Hunter et al. 2012). The cooling benefits can be especially pronounced for green façade designs that maintain an insulating layer between the building surface and vegetation. Studies in humid subtropical climates indicate that building surface temperatures behind vegetated walls can be 21-36° F cooler than non-vegetated walls on hot sunny days (Alexandri and Jones 2008, Chen et al. 2013, Mazzali et al. 2013), which in turn leads to reduced energy loads for building climate control. Furthermore, the temperature effects can extend to the adjacent street "canyons," reducing air temperatures by around 7° F (Alexandri and Jones 2008). The cooling benefits vary with individual plant species characteristics, including physiology and leaf area (Cameron et al. 2014).

Vegetated walls can also provide air quality benefits in urban landscapes, including capture of particulate matter and uptake of O_3, NO_2, and SO_2 (Currie et al. 2008, Pugh et al. 2012). The cooling benefits they provide can also reduce formation of ground-level O_3. The vegetation in green façades also reduce noise pollution and act as sound insulation tools for buildings (Azkorra et al. 2015).

In addition, vegetated walls can be designed specifically to provide foraging or nesting resources for local wildlife species (Francis 2011). They show promise for supporting arthropod species (i.e., beetles and spiders) and urban bird species (i.e., house sparrows and European starlings) (Chiquet et a. 2013, Madre et al. 2015).

5.2 Economic Benefits

The economic benefits of green walls have not been studied as extensively as green roofs. They provide similar types of benefits, but from the literature available to date, the magnitude of benefits appears to be smaller, and costs higher. However, for taller buildings, some studies have suggested that green walls be used in conjunction with or instead of green roofs to produce maximum economic benefits. For example, the GSA found that "Simultaneous use of green roofs and green walls is significantly more effective than the use of green roofs alone in reducing surface and ambient air temperatures in urban canyons and over rooftops." (GSA 2011 pg. 34)

Green walls generate both public and private benefits. Economic benefits to the building owner arise from the insulating and protective properties of the wall system: the vegetation can reduce energy demand for heating and cooling and increases the lifespan of the exterior façade, increasing the time between required maintenance. Green walls also provide aesthetic benefits that may increase the property value or rent a building owner may charge. The performance and associated economic benefits of green walls depends in part on choosing vegetation appropriate for the local climate conditions. Using vegetation not suited to the climate may increase costs associated with additional maintenance and irrigation.

Much of the economic research on green wall systems comes from Europe. One study looked at the benefits and costs of several theoretical green wall installations in Genoa, Italy (Perini 2013). This study found the green wall could increase property value by 2 to 5 percent, with the highest increase for buildings located in the periphery of the city. Energy savings in the Mediterranean climate where the hypothetical building would be located resulted from reduced air conditioning. Maximum benefit depended on the existing insulation of the building, with all concrete-walls benefiting the most (up to 65.8 percent), and walls with polystyrene insulation already in place benefiting the least (1.4 to 2.6 percent energy use reduction). The green wall systems also increased the lifespan of the building façade (plaster) from 35 years to 50 years. The study examined the literature on social benefits (e.g., air quality improvement, urban heat island effect, and biodiversity) but found limited data to support the quantification of benefits on a single-building scale. Overall, the study found that green wall systems with the lowest installation cost (green walls versus living walls) had a positive rate of return to the building owner, but in no scenario, did the living wall system produce positive net benefits because of its ongoing maintenance costs.

Another benefit-cost analysis of a living wall system on a school in Dubai found that the system produced a yearly cooling savings of 18 percent, and an increased rental rate (Haggag and Hassan 2015). However, with these quantified benefits, the payback period for the building owner would be 17 years under current energy prices. This study did not consider other private benefits, such as increased longevity of the building façade or public benefits, such as air quality improvement.

The public benefits discussed but not quantified in the economic literature include reduced urban heat island effect, improved exterior air quality (green walls installed indoors can improve interior air quality as well), aesthetic improvements, biodiversity, and noise reduction (Green Roofs for Healthy Cities 2008). Stormwater capture is rarely mentioned as a benefit of green walls, but some specifically designed examples do exist (see e.g., City of Portland 2014).

5.3 Beneficiaries

Building owners and occupants are the primary beneficiary of green walls, with some aesthetic benefit accruing to pedestrians and adjacent property owners in view of the green wall installation. Most of the public benefits associated with individual green walls are too small to make a noticeable difference in factors such as the urban heat island and air quality. However, the incremental improvement of individual installations could add up if green walls are more widely adopted, leading to measurable public benefits.

5.4 Costs of Implementation

Green wall systems vary in installation costs, depending on their design. Livings walls are typically more expensive to install and maintain than green façades using ground-level plantings. Installation costs can range from approximately \$80 to \$150 per square foot for livings walls (Liang 2014). Maintenance costs for living walls can range from \$7 to \$15 per square foot. Installation for green facades can range from \$25 to \$40 per square foot or more, which includes installation of the climbing structure, substrate, plants, and irrigation systems (Architek No Date; State of Victoria 2014; Perini and Rosasco 2013). Annual maintenance costs for green façades are not widely documented in the literature, but are typically cited as minimal (\$0.25 to \$1 per square foot, Perini and Rosasco 2013). Typical activities, such as pruning, plant replacement if necessary, and debris clearing are often covered in landscape budgets. Other activities, such as structural inspection, occur infrequently, if at all. Maintenance costs are higher for green wall systems in climates that require irrigation, because water charges would accrue and the irrigation system would need additional annual maintenance and repair. These are still fairly new systems, and engineering challenges in installation and maintenance remain for many applications. Costs may decline as green walls gain wider acceptance, as was the case for green roofs (Rizer 2014).

6 Porous pavement

6.1 Biophysical Benefits

Porous pavement promotes retention of stormwater by allowing water to permeate the surface layer and infiltrate into underlying substrate, which can in turn reduce pollutants and recharge groundwater. A variety of porous pavement systems exist, including permeable interlocking concrete pavers, concrete grid pavers, open-jointed block pavement, and porous asphalt. In some types of porous pavement, vegetation can grow between paving units and promote cooling through evapotranspiration.

Research on stormwater management performance indicates that porous pavements substantially reduce runoff volume and peak flow rates. Studies from humid subtropical climates in North Carolina, Florida, and Georgia, USA have demonstrated that porous pavement can reduce runoff volumes by more than 90 percent and can eliminate runoff entirely for small storms (Rushton 2001, Collins et al. 2008, Dreelin et al. 2006, Bean et al. 2007, Ball and Rankin 2010). In general, green infrastructure such as green roofs, bioretention, and porous pavements experience saturation and therefore provide little benefit in large storms and flash flood events. A modeling study for an Austin watershed demonstrated that incorporating porous pavement as part of a broader green infrastructure implementation plan could lead to reduced runoff volumes, reduced peak flow rates, increased groundwater recharge, and reduced pollutant loads, although the relative contribution of porous pavement was minor compared to other green infrastructure types (Geosyntec 2016).

The benefits for water quality vary between studies, indicating that performance depends on a variety of factors related to design and precipitation. The International Stormwater BMP Database 2014 statistical summary report indicates that porous pavements are associated with statistically significant reductions in total suspended solids, total phosphorus, and some metals (copper, lead, nickel, and zinc).

Porous pavements can also provide cooling benefits, but results from previous studies have been inconclusive. In general, porous pavements can have a cooling effect when the retained water evaporates; however, when the water is depleted, the pavement surface can be hotter than conventional pavements (Santamouris 2013). In addition, porous pavements generally have a lower albedo than impermeable types. Results from studies in Arizona, South Carolina, and Iowa, USA demonstrate that porous pavements can reach higher daytime surface temperatures than other pavements, but they also cool to lower temperatures overnight (Caslon et al. 2009, Haselbach 2009, Kevern et al. 2009).

6.2 Economic Benefits

Porous pavement generates economic benefits primarily through the stormwater retention effect, reducing the need for other types of stormwater infrastructure. These benefits are described in more detail for Austin under the Bioretention section above.

Depending on the type of material used, the porous material may cost less to install, resulting in a reduced cost of development (Century West Engineering No Date). The cost savings comes from several sources. First, on street and parking lot applications, porous pavement may eliminate the need for standard curbs, gutters, storm drains, piping, and retention basis. Second, because extensive stormwater infrastructure is not required, less land is needed to manage the stormwater (i.e., detention basis are not required) so it may be put to other uses (ConcreteNetwork.com 2017).

Porous pavement applications that would not typically require stormwater management infrastructure (i.e., sidewalks, pedestrian areas) would not likely result in similar cost savings to developers. The economic benefit for these areas would primarily be in the form of reduced public stormwater infrastructure costs and reduced flooding, as described above.

6.3 Beneficiaries

For porous pavement installed on private property, the property owner would enjoy any cost savings that materializes from choosing porous pavement over conventional pavement, primarily the cost savings that comes from reduced drainage system requirements. The public (i.e., taxpayers) would enjoy the benefits of reduced public stormwater infrastructure, if a porous pavement installation reduced the need for stormwater retention on public property.

6.4 Costs of Implementation

Tables 5 shows the costs of instillation and O&M for porous pavement in City of Austin.

Table 5: City of Austin Cost of Porous Pavement Installations

	Low Cost ($/SF)	Average Cost ($/SF)	High Cost ($/SF)	Annual Average O&M ($/Instillation)
Porous Pavement	$6.34	$9.88	$18.55	$678

Source: City of Austin staff, Personal Communication, January 17, 2017.

Porous materials are even more cost competitive in larger applications and for areas where conventional alternatives would require stormwater retention infrastructure.

7 Cisterns

7.1 Biophysical Benefits

A cistern is an above- or below-ground tank that collects and stores rainwater for reuse. The biophysical benefits of cisterns include reducing stormwater volume and peak flow rates, which can in turn contribute to improved ecological health of urban streams. In addition, the water collected in a cistern can be reused for landscape purposes, which reduces the need for potable water in irrigation. Two Austin-based modeling studies included cisterns as part of broader green infrastructure implementation scenarios and demonstrated that cisterns could play a substantial role in reducing peak flow rates and total runoff volumes in Austin watersheds (Glick et al. 2016, Geosyntec 2016). In most urban landscapes, a multi-pronged strategy of stormwater harvesting (e.g., with cisterns) combined with infiltration (e.g., with biofiltration) will be required to achieve stormwater targets and improve urban stream health (Askari et al. 2015, Burns et al. 2015). The stormwater management benefits of cisterns can be an important strategy to reduce the "flashiness" of flow in urban streams and lead to improvements in stream health, including reduced flooding, reduced erosion, and improved aquatic life. Cisterns would need to be emptied prior to large storage events to provide additional storage.

7.2 Economic Benefits

Cisterns provide economic benefits through stormwater capture and reuse. When stormwater is captured in cisterns, the risk of flooding and economic damage from flood events decreases. Since they serve to capture and hold water, less stormwater retention infrastructure may be required. However, for this latter benefit to be realized, the tanks must be reliably maintained and used (e.g., after a rainfall event they must be drained and ready to capture the next rainfall event). The other economic benefit cisterns provide is water supply, which can be used for non-potable applications, such as lawn watering, or in some cases can be coupled with treatment to supply a wider range of uses.

The economic benefits that cisterns generate related to reduced flood damage or avoided retention infrastructure costs depend on how widely cisterns are adopted and how much stormwater they are capable of capturing. These benefits materialize at a meaningful level when cistern use is widespread or targeted in areas where flooding is a problem.

Passive rainwater harvesting systems, such as rain barrels, provide limited opportunities for significant runoff reduction due to relative small volumes and unpredictable operational readiness when a storm occurs (EPA 2013). This dramatically limits the economic benefits that cities can realize in the form of reduced retention infrastructure: primary stormwater capture infrastructure must still be built. Moreover, passive capture systems typically satisfy only a small fraction of the water demand of a typically homeowner, even for landscape irrigation.

Active cistern systems are larger volume systems (between 1,000 and 100,000 gallons) that capture and provide water supply. These are more appropriately scaled to multi-family dwelling units. They can range from simple, gravity-fed systems that provide untreated water for landscaping purposes to complex systems with treatment and pressure to supply a distribution system, for potable or gray-water use. The latter systems can supply a wider range of uses (EPA 2013). If the primary goal for cistern use is stormwater capture, the system must have a reliable source of demand, so that it can be drained prior to a storm. Some systems connect to backup stormwater management controls, such as a rain garden or the stormwater system itself, and empty stored water at low-flow periods to ensure adequate storage capacity for the next rainfall event. Automated monitoring systems are available to control the cistern capacity and time releases to weather events.

Optimal cistern sizing takes into consideration the local climate and water demand. A study of cisterns in Austin found that the maximum tank size to capture all available runoff in an average year in Austin would be 7,000 gallons. A tank this size would provide 46 percent of the typical water demand from a household in Austin (Kim 2011).

The economic benefits in water savings from these active systems would accrue slowly: the annual savings in water purchases of a system of this scale is in the low-hundreds of dollars per year. When a cheap, reliable source of water is available from the public water provider, cisterns do not compete economically. However, when water reliability becomes an issue, cisterns provide their owners with assurance that water will be available. This reliability factor has an economic value, which depends on the cost of obtaining alternative supplies of water and the individual's willingness to accept different levels of reliability from the public system.

7.3 Beneficiaries

Cistern owners enjoy private benefits in the form of reduced water purchases and potentially increased water reliability if public water shortages occur. The public may enjoy benefits to the extent that cisterns reduce the peak flow of stormwater events, reducing the risk of flood damage for public and private property owners, and potentially reducing the investment required in stormwater retention infrastructure on public property.

7.4 Costs of Implementation

A small-scale rain barrel system that might be purchased from a hardware store and self-installed runs between $2 and $3 per gallon (City-Data 2010; EPA 2013). Active cistern systems are much more expensive. Large cisterns typically cost between $1.50 and $3.00 per gallon of storage. The rest of the system can vary significantly in cost, depending on the pumps, treatment systems, and distribution systems selected. The additional cost is typically between $2.00 and $5.00 per gallon but could be much more. The 7,000-gallon system specified by Kim (2011) for Austin costs between $7,500 and $12,000 (2016$). Operation and maintenance also varies depending on the system, ranging from virtually no maintenance at all for a simple rain barrel, to around $800 per year for routine maintenance and $350 per year for infrequent maintenance activities.

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Regenerative Environmental Design

Date: January 18, 2017

To: Austin City Staff

From: Heather Venhaus, RED

Amy Belaire, PhD

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Subject: Results of Task 7C: Existing Program Analysis

1.0. Introduction

This report summarizes the key findings from an analysis of existing programs that are similar to City of Austin's Functional Green program. Six programs from Europe and the United States were evaluated. Each of these programs requires urban developments to incorporate landscape elements that enhance ecological function of cities; however, the details of each program vary from city to city. This analysis was conducted by reviewing relevant literature and interviewing key personnel associated with each program. A comparison chart of the programs can be found in Appendix A. In the report below, we discuss details of each program individually, including how the program was developed, which landscape elements are included, and how development scores are calculated. Furthermore, we summarize the "lessons learned" from the existing programs around the world and highlight important recommendations for the City of Austin in its process of developing a similar program.

1.1 Overview of existing programs: the basics

A Biotope Area Factor, also known as a Green Space Factor or Green Area Ratio, is an environmental metric and planning tool for urban green space. The metric was developed to increase the ecological performance and vegetated area of urban environments. Biotope Area Factor (BAF) has been in use in Europe since the 1990's and represents the ratio between ecologically effective surface area and the total project area. To calculate the performance rating, the total area of each landscape element is determined and then multiplied by an established factor. The value of each landscape element is summed and then divided by the total area of the site.

$$\text{BAF} = \frac{(\text{area A x factor A}) + (\text{area B x factor B}) + (\text{area C x factor C})}{\text{total site area}}$$

The factors assigned to the different landscape elements vary based upon their relative environmental performance and aesthetic value. Landscape elements that address certain ecosystem services identified as a priority are typically given higher factors.

Minimum BAF target scores vary depending on building type and location. Target scores represent the minimum percentage of a site that must provide ecosystem services. The goal is to set realistic minimum levels that can be achieved on most projects while also increasing the ecosystem service benefits provided. In general, target project scores are determined through comparison studies of existing landscape code and BAF requirements, experimental design case studies that explore the green potential of sites, and the goals of city planners. Pilot phases are conducted to test and refine as needed. BAF plan review is typically part of the building permit application process. After a project has been approved, property owners are typically not required to resubmit plans for approval when landscape changes occur. However, property owners are expected to continually maintain landscapes in a manner that support BAF objectives.

1.2. BAF research gaps & leadership opportunity

Reports and guidance documents related to the BAF tools reviewed in this report note the environmental benefits of the landscape elements (e.g., vegetated walls provide high transpiration efficiency, high binding of dust and high significance as a habitat for animals). However, none of the programs provide literature reviews of the science that informed decisions or discuss the process that was used to determine the value of the landscape elements to the owner and community at large. Supporting documentation for these tools also lacks details regarding the estimated performance and post-occupancy monitoring of the BAF projects. The City of Austin is taking a leadership role by documenting the scientific evidence for ecosystem service benefits that influence the proposed weights of the landscape elements in Functional Green. Additional opportunities exist to contribute to the continued improvement of BAF tools by providing methods to estimate performance and gathering post-occupancy information. This data will be necessary to document ecosystem service benefits provided to the community and to enable the continual improvement of Functional Green.

2.0 Berlin, Germany Biotope Area Factor (BAF)

The first Biotope Area Factor was developed by the City of Berlin in response to strong public desire to reduce environmental impacts and to provide green space in dense urban areas (Berlin, 2016). It has been in use since 1997 and is the inspiration for similar programs around the world.

The BAF is applied in select parts of Berlin to all forms of urban development with target factors ranging from 0.6 for new residential units, public facilities and day care complexes to 0.3 for commercial sites, schools and technical infrastructure (Berlin, 2016). Whereas it is the intent of the program to build more ecologically robust sites, Berlin administrators routinely reduce minimum target factors in situations where target fulfillment results in exceptional costs or in cases involving special status properties such as historic buildings, schools or transits hubs (Kelley 2011).

Landscape element weights or multiplication factors were based on the perceived ecological effectiveness of each element in regards to the following areas: 1) improvement of the microclimate and air quality, 2) soil function, 3) efficiency of water management and 4) an increase in plant and animal habitat (Becker Giseke Mohren Richard 1990).

One unique component of Berlin's BAF is the score of 1 given to all vegetated surfaces regardless of the plant type. Some consider this a weakness of the program due to the variation in ecosystem service benefits provided by different vegetation types (for example, trees vs. lawns). However, one potential benefit of this strategy is that a uniform point value for all vegetated areas greatly simplifies project calculations. Point values increase for vegetated ground surfaces with deeper soils and connection to subsoils. Roof area that is not green roof can be also gain points if the stormwater drains to a vegetated surface that provides infiltration (Berlin, 2016).

Post-occupancy monitoring of the BAF has been virtually non-existent (Keeley 2011), however over the course of the last 20 years the Berlin City Planning Department has observed widespread acceptance of the program. Germany's federal laws serve as a strong legal foundation for BAF aiding in its adoption. In addition to the support of the German people, the success of the BAF can be contributed to three primary factors (Keeley 2011):

- Clarity of the requirements and permitting process

- Flexibility in design choices
- Dual compliance, where BAF meets other city requirements and can lead to reduced fees such as stormwater

3.0 Malmö, Sweden Green Space Factor (GSF)

The city of Malmö adapted Berlin's BAF for the redevelopment of Western Harbour, a 395-acre environmentally sustainable urban district designed to showcase the most innovative strategies for construction and design. The first completed stage of the development was the neighborhood Bo01, which had a minimal target score of 0.5. Evaluation and monitoring of Bo01 concluded that most of the development achieved the target score. This prompted an increase in the minimal target to 0.6 for the remainder of the development. Reviewers noted that built projects with lower than planned scores were typically the result of the failure to replace dead vegetation resulting in a less vegetation (Kruuse 2011). The GSF differs from Berlin's BAF in the weights assigned to different vegetation types and in the potential to layer landscape elements to achieve a greater score. In addition, the program added the concept of Green Points to improve the overall quality of the landscape. A list of 35 Green Points are given to developers who must implement 10 of them. Options include items such as bird and bat boxes, nectar rich gardens that provide a variety of food for butterflies ("butterfly restaurant"), no-mow lawns, frog habitat, greywater reuse and the cultivation of food crops. A full list of the Green Points can be found in Appendix B.

4.0 Seattle Green Factor (SGF)

Seattle was the first city in the United States to implement a biotope area factor. In 2006, Seattle revised the code standards for urban village commercial zones and adopted the Seattle Green Factor. The SGF is intended to increase the quality and quantity of urban landscaping. SGF requirements have been extended to other portions of the city, with targets of 0.3 for commercial, neighborhood and industrial commercial, 0.5 for midrise and highrise multifamily residential, and 0.6 for lowrise multifamily residential (Seattle, 2016). Steve Moddemeyer, principal author of the Seattle Green Factor, describes the code as a logical trade-off, requiring developers to be more responsible for their impacts in exchange for height restriction relief (S. Moddemeyer, personal communication, Dec. 9, 2016).

4.1 Landscape elements in SGF

Seattle's Green Factor scoring encourages the layering of vegetation with planting areas earning more for the addition of understory. At least 25% of all plantings must be drought-tolerant. Due to the cost savings compared to other landscape elements, project teams pursuing SGF typically begin by adding vegetation to the greatest extent possible (D. LaClergue, personal communication Nov. 29, 2016).

Biofiltration facilities are given credit for the entire area including the sides and bottom of the feature. The value of permeable paving varies with the depth of the soil or gravel reservoir. A cap has been placed on the number of points that can be received from only one landscape element to encourage a variety of design solutions.

As of 2010, there were approximately 200 projects that achieved SGF. Seventy-five percent of these included green walls, 50% included green roofs, 50% included permeable paving, and every project has at least one of the three (ASLA, 2016). Green roofs and permeable paving are frequently applied due to joint benefits, which also meet stormwater management code requirements. Vegetated walls are also common due to the limited area of urban sites. Water features and food cultivation are the landscape elements used least often. This is thought to be due to the high maintenance requirements of edible landscapes and that 50% of the annual flow for water features must be derived from harvested rainwater (D. LaClergue, personal communication Nov. 29, 2016).

One significant difference that sets the SGF apart from the Malmö and Berlin metrics is the addition of bonus points. Bonus points are given for drought-tolerant or native plants, landscape areas where at least 50% of annual irrigation needs are met through the use of harvested rainwater, landscaping visible to passersby from adjacent public rights-of-way or public open spaces, and food cultivation.

The public right-of-way is not counted in parcel size calculations; however, landscape improvements in rights-of-way contiguous with the parcel may be counted (Seattle, 2016). In addition, a landscape professional must prepare a Landscape Management Plan that includes direction for soils, irrigation, pest control, water features, and vegetation.

4.2 Score factors in SGF

Landscape elements in SGF were weighted according to relative aesthetic and functional values, as determined by the SGF development team which included local site designers, city staff, and land planners (S. Moddemeyer, personal communication, Dec. 9, 2016). A Seattle Green Factor Score Sheet has been provided in Appendix C. SGF came out of the tradition of aesthetic development standards and is not performance driven like other Seattle regulations (D. LaClergue, personal communication Nov. 29, 2016). The program requires extensive collaboration between various city departments due to planting options in both rights-of-way and on private property as well as the implementation of stormwater BMPs.

4.3 Target scores in SGF

The minimum score for new development was determined through a series of case studies conducted by local design firms using existing projects (both typical and high performance) built under conventional City of Seattle standards. The firms also evaluated which additional landscape elements could be reasonably added to the sites. Existing commercial projects achieved scores between 0.05 and 0.15. A minimum score of 0.3 was then set as a reasonable target for commercial projects to provide greater results. It was estimated that the SGF would increase total building costs by roughly 0.5% (S. Moddemeyer, personal communication, Dec. 9, 2016).

4.4 Program success

Overall, the SGF landscapes are thought to be more attractive and better integrated into site programs than conventional landscapes. SGF has encouraged landscape design as part of the initial stages of site planning resulting in more collaboration between design professionals (D. LaClergue, personal communication Nov. 29, 2016). The adoption of the SGF has been relatively smooth because it has been integrated with other zoning changes where the benefits to developers outweigh the Green Factor costs. Success has also been due to extensive collaboration with and education opportunities for design professionals to help communicate requirements to clients and the general public (S. Moddemeyer, personal communication, Dec. 9, 2016).

5.0 Stockholm Biotope Area Factor

A biotope area factor for Stockholm Royal Seaport, an industrial redevelopment site, was developed to identify ecosystem services, to encourage the strengthening of local ecosystems, and to create climate-adapted courtyards with high social values (Block and Bokalders 2016).

Development of the 583-acre environmentally sustainable neighborhood began in 2010.

The planning tool is based on Malmö's GSF; however, refinements were made to include more detailed landscape options that support biodiversity, climate adaptation, and the social use of green space. Points can be awarded for landscape elements such as "butterfly restaurants" (pollinator gardens), fruit-bearing vegetation, beetle and bird feeders, shared roof terraces, and grass areas suitable for games and playing (Block and Bokalders 2016). The result is a greater variety of design outcomes but a potentially more complicated assessment tool. A scoring sheet showing the full range of landscape elements has been included in the Appendix D.

6.0 Washington DC Green Area Ratio (GAR)

Washington, DC, initiated a Green Area Ratio program in 2013. The GAR was created to promote greater livability, ecological function, and climate adaptation in the urban environment. The program primarily focuses on elements that benefit air and water quality and reduce the urban heat island. Washington, DC, is a quickly-developing city with strict stormwater requirements. The GAR reinforces other areas of development code and is a horticultural overlay to existing stormwater regulations (S. Gyor personal interview Dec. 2, 2016).

All new buildings that require a Certificate of Occupancy must meet the appropriate Green Area Ratio based on zoning district. Minimum targets range from 0.1 – 0.4. The program excludes single-family residences, water treatment facilities, and some historic sites. Sites can qualify for a reduced GAR score via special exception if sustainability goals are met through means outside the scope of the program (Cidlowski et al. 2013).

6.1 Landscape elements in GAR

Similar to Seattle, the GAR encourages deeper soils and the layering of vegetation. The City provides recommended specifications for soils and plan submittals require detailed soil testing and installation information. The most commonly applied landscape element is the green roof. City staff note that green roofs are given a high ranking even though they are only visible to a small percentage of the population. To increase the number of green roofs that are visually accessible to the public, the program could provide bonus points for green roofs that are visible to the public. The second most used landscape elements are ground plane plantings and increased soil volume. Many developers take the 24" soil depth option that was developed to encourage trees (S. Gyor personal interview Dec. 2, 2016). No credit is given for trees in rights-of-way. The least commonly used landscape element is green walls due to high installation costs and the limited GAR scoring benefits. The tool is being updated to include the vertical wall area in addition to the base planting (S. Gyor personal interview Dec. 2, 2016). Biofiltration facilities square footage includes the pretreatment area and filter bed. Side slopes are not included in the calculations. Only one-third of the overall Green Area Ratio score can be derived from permeable paving and structural soils.

A bonus multiplier is given for native plant species, food cultivation, and harvested stormwater irrigation. To receive the harvested rainwater irrigation credit, a minimum of 50% of the annual usage must be supplied by stormwater. Water features must receive 50% of their annual flow from harvested rainwater and must hold water a minimum of 6 months of the year. To achieve the food cultivation bonus, the areas credited must continue to grow food Spring through Fall. Animal cultivation is not allowed. City staff noted the need to better define native plants and to allow the use of cultivars (S. Gyor personal interview Dec. 2, 2016). A landscape maintenance plan signed by a

Certified Landscape Expert is submitted with the plan set and must include activities and schedules for each landscape element. The City provides recommended maintenance activities and timelines for each landscape element that can be amended by the Landscape Expert.

The GAR is unique in that it provides credit for renewable energy using PV and solar thermal systems. This option was included because it provides a benefit to the city and is relatively easy for developers to implement (S. Gyor personal interview Dec. 2, 2016). Other programs do not include renewable energy. This is thought to be due to the fact that the BAF is typically part of a city's landscape code and incentives for renewable energy exist in other areas. In addition, allowing credit for renewable energy will reduce the overall area of other landscape elements. A Green Area Ratio Score Sheet has been included in Appendix E.

6.2 Program rollout of GAR

Overall, the program has been a success due in part to the significant comment period and public workshop meetings that allowed input from designers and developers. Social media and blogs were also successful at communicating the simplicity and flexibility of the tool. City staff noted that it is common for projects that are not eligible for exemption to seek exemption (S. Gyor personal interview Dec. 2, 2016). The *Green Area Ratio Guidebook*, which was released with the regulations, has been essential in helping project teams understand the program and clarify requirements. The submittal process was intentionally designed for ease of review and can be handled entirely on-line. City inspectors would like to see more pre-development and pre-construction meetings with applicants to ensure the feasibility of their plans. It is also recommended that inspectors be part of the review process and that site inspections occur throughout the construction process, not just at the end of the project.

7.0 North West England Green Infrastructure Toolkit

This guidance tool was adapted from Malmö's Green Space Factor and supports green infrastructure objectives. It is included in this report because of its unique approach to establishing target requirements that reflect the existing conditions of the site. Projects with pre-existing structures or hardscape must score at least 0.2 points higher than the existing site conditions. Sites without pre-existing structures have a requirement of 0.6. Flexibility in scoring was given to reflect additional difficulty that may exist for projects with existing urban forms (Kruuse 2011). This type of scoring may be useful to Functional Green and projects that are not complete redevelopments of the site.

8.0 Recommendations and follow up questions:

1. Recommendations related to landscape elements, weighting, and target score
    a. Provide a bonus credit for landscape elements that are physically or visually accessible to the general public to extend benefits to the larger community.
    b. Target goals must be reasonable for most developments. Target conditions that stress high performance will improve environmental conditions; however; if the targets are too onerous, they can discourage dense development and push construction to less desirable areas where Functional Green is not required.
    c. Consider assigning additional weight to landscape strategies that provide human enjoyment benefits and encourage

pedestrian traffic, such as shaded places to play, walk, eat or rest.

d. Limit the portion of a target score that can be met with a single strategy such as permeable paving and green walls.
e. When considering landscape element weighting options, it is important to note that larger multipliers/values can result in a reduced area coverage of that landscape element. In other words, high ranking values intuitively decrease the overall size of that landscape element. Low ranking values encourage more square footage of a landscape element (S. Moddemeyer, personal communication, Dec. 9, 2016).
f. There are always landscape elements to be added or improved upon. Provide for the ability for the program to be easily adjusted over time (S. Gyor personal interview Dec. 2, 2016).

3. Recommendations for implementing and administering the program
   a. Conduct a pilot project phase to test assumptions and make adjustments where needed.
   b. Performance standards are difficult to administer and typically require more highly-trained administrative staff. Map how different city departments work together. Determine communication, responsibility, and decision channels in advance. Provide additional education to review staff and field inspectors (D. LaClergue, personal communication Nov. 29, 2016 and Gyor).
   c. Functional Green should balance the economic costs with the gains of increased building density and square footage.
   d. On-going maintenance that ensures continued attainment of original performance goals is a problem for all the BAF tools. Shoup (1996) recommends additional triggers for compliance

review such as the re-review upon the sale of property or of an issuance of building permits. In addition, a Landscape Maintenance Plan submitted to the owner should be required.

e. Explore the potential to use energy conservation dollars within the city to enhance urban green and reuse. If you can get a small reduction in energy use, the city's utility can incentivize specific strategies (S. Moddemeyer, personal communication, Dec. 9, 2016).
f. Provide opportunities for pre-design and pre-construction meetings with the city to ensure compliance. Provide inspections throughout construction not just at the end of the project. Inspectors should be part of the review process (S. Gyor personal interview Dec. 2, 2016). Can additional reviews be incentivized by an expedited process?

3. Recommendations related to outreach and education about the program
    a. Highlight where compliance meets other City requirements, such as stormwater, in public education materials and talks.
    b. Educational materials such as guidebooks are essential to early adoption and ease of communication. These tools should be released at the same time as Functional Green.
    c. Communicate benefits to the various stakeholder groups including developers.
    d. Recommend looking at Sustainable Sites Initiative (SITES) and similar programs to illustrate how Functional Green can help developers meet other goals. Communicate to design teams and owners how the BAF can support project certification (D. LaClergue, personal communication Nov. 29, 2016).

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Appendix

Appendix A: Program comparison

Landscape Elements	Berlin BAF	Malmo GSF	North west England Green Infrastructure Toolkit	Seattle GF	Stockholm BAF *	Washington GAR
Target	0.6 for new residential, public facilities and day care complexes, 0.3 commercial and schools	0.6 - Redevelopment of Western Harbour, an urban district meant to showcase environmentally sustainable practices.	0.6 for vacant plot development, a +0.2 difference from pre-developed phase for renovations.	0.3 for commercial, neighborhood and industrial commercial, 0.5 midrise and highrise multifamily residential, and 0.6 for lowrise multifamily residential	0.6 - Royal Urban Seaport , environmentally sustainable neighborhood	0.1 - 0.4. New buildings that require a Certificate of Occupancy must meet the appropriate target based on the zoning district
Year established	1997	2001	2011	2006	2010	2013
Bioretention facility	0.2	0.2	0	1	0.1 - 2.0	0.4
Drought tolerant or native plants	0	0	0	0.1	0	0.1
Food cultivation	0	0	0	0.1	0	0.1
Green roof	0.7	0.6	0.7	0.4 - 0.7	0.1 - 0.4	0.6 - 0.8
Harvested rainwater	0	0	0	0.2	0	0.1
Landscape visibility to passerbys	0	0	0	0.1	0	0
Ground cover	1			0.1	2	0.2
Permeable paving	0.3-0.5	0.2 - 0.4	0.2-0.4	0.2 - 0.5	0.05 - 0.3	0.4 -0.5
Tree preservation	1	0	0	0.8	0.2 - 3	0.7 - 0.8
Renewable energy generation	0	0	0	0	0	0.5
Sealed surface	0	0	0	0	0	0
Shrubs or perennials	1	0.2	0.3	0.3	0.1 - 0.4	0.3
Soil depth < 24"		0		0.1	0	0.3
Soil depth > 24"	0.5 - 0.7	0	0.4 - 1	0.6	0	0.6
Structural soils	0	0	0	0.2	0	0.4
Tree large	1	2	0.4	0.4	2.4	0.6
Tree medium	1	1.5	0.4	0.3 - 0.4	2.5	0.6
Tree small	1	1	0.4	0.3	1	0.5
Vegetated walls	0.5	0.7	0.6	0.7	0.4	0.6
Water feature	0	1	1	0.7	0	0.2

*** The Stockholm Biotope Area Factor is difficult to compare to the other programs because the landscape element options are significantly different. The program places an unique emphasis biodiversity, climate adaptation and the social use of green space. See Appendix D for more details.**

Appendix B: Green Points

- A bird box for every apartment
- A biotope for specified insects in the courtyard (water striders and other aquatic insects in the pond)
- Bat boxes in the courtyard
- No surfaces in the courtyard are sealed, and all surfaces are permeable to water
- All non-paved surfaces within the courtyard have sufficient soil depth and quality for growing vegetables
- The courtyard includes a rustic garden with different sections
- All walls, where possible, are covered with climbing plants
- There is 1 square metre of pond area for every 5 square metres of hard-surface area in the courtyard
- The vegetation in the courtyard is selected to be nectar rich and provide a variety of food for butterflies (a so-called 'butterfly restaurant')
- No more than five trees or shrubs of the same species
- The biotopes within the courtyard are all designed to be moist
- The biotopes within the courtyard are all designed to be dry
- The biotopes within the courtyard are all designed to be semi-natural
- All stormwater flows for at least 10 metres on the surface of the ground before it is diverted into pipes
- The courtyard is green, but there are no mown lawns
- All rainwater from buildings and hard surfaces in the courtyard is collected and used for irrigation
- All plants have some household use
- There are frog habitats within the courtyard as well as space for frogs to hibernate
- In the courtyard, there is at least 5 square metres of conservatory or greenhouse for each apartment
- There is food for birds throughout the year within the courtyard
- There are at least two different old-crop varieties of fruits and berries for every 100 square metres of courtyard
- The facades of the buildings have swallow nesting facilities
- The whole courtyard is used for the cultivation of vegetables, fruit and berries
- The developers liaise with ecological experts
- Greywater is treated in the courtyard and re-used
- All biodegradable household and garden waste is composted
- Only recycled construction materials are used in the courtyard
- Each apartment has at least 2 square metres of built-in growing plots or flower boxes on the balcony

Appendix B: Green Points continued

- At least half the courtyard area consists of water
- The courtyard has a certain colour (and texture) as the theme
- All the trees and bushes in the courtyard bear fruit and berries
- The courtyard has trimmed and shaped plants as its theme
- A section of the courtyard is left for natural succession (that is, to naturally grow and regenerate)
- There should be at least 50 flowering Swedish wild herbs within the courtyard
- All the buildings have green roofs

Appendix C: Seattle Green Factor Score Sheet

Revised 12/28/10

Green Factor Score Sheet

SEATTLE×green factor

Project title:

	Parcel size *(enter this value first)* *	*enter sq ft of parcel* 5,000		SCORE	-
	Landscape Elements**	**Totals from GF worksheet**		**Factor**	**Total**
A	**Landscaped areas (select one of the following for each area)**				
1	Landscaped areas with a soil depth of less than 24"		*enter sq ft* 0	0.1	-
2	Landscaped areas with a soil depth of 24" or greater		*enter sq ft* 0	0.6	-
3	Bioretention facilities		*enter sq ft* 0	1.0	-
B	**Plantings (credit for plants in landscaped areas from Section A)**				
1	Mulch, ground covers, or other plants less than 2' tall at maturity		*enter sq ft* 0	0.1	-
2	Shrubs or perennials 2'+ at maturity - calculated at 12 sq ft per plant (typically planted no closer than 18" on center)	*enter number of plants* 0	0	0.3	-
3	Tree canopy for "small trees" or equivalent (canopy spread 8' to 15') - calculated at 75 sq ft per tree	*enter number of plants* 0	0	0.3	-
4	Tree canopy for "small/medium trees" or equivalent (canopy spread 16' to 20') - calculated at 150 sq ft per tree	*enter number of plants* 0	0	0.3	-
5	Tree canopy for "medium/large trees" or equivalent (canopy spread of 21' to 25') - calculated at 250 sq ft per tree	*enter number of plants* 0	0	0.4	-
6	Tree canopy for "large trees" or equivalent (canopy spread of 26' to 30') - calculated at 350 sq ft per tree	*enter number of plants* 0	0	0.4	-
7	Tree canopy for preservation of large existing trees with trunks 6"+ in diameter - calculated at 20 sq ft per inch diameter	*enter inches DBH* 0	0	0.8	-
C	**Green roofs**				
1	Over at least 2" and less than 4" of growth medium		*enter sq ft* 0	0.4	-
2	Over at least 4" of growth medium		*enter sq ft* 0	0.7	-
D	**Vegetated walls**		*enter sq ft* 0	0.7	-
E	**Approved water features**		*enter sq ft* 0	0.7	-
F	**Permeable paving**				
1	Permeable paving over at least 6" and less than 24" of soil or gravel		*enter sq ft* 0	0.2	-
2	Permeable paving over at least 24" of soil or gravel		*enter sq ft* 0	0.5	-
G	**Structural soil systems**		*enter sq ft* 0	0.2	-
		sub-total of sq ft =	*0*		
H	**Bonuses**				
1	Drought-tolerant or native plant species		*enter sq ft* 0	0.1	-
2	Landscaped areas where at least 50% of annual irrigation needs are met through the use of harvested rainwater		*enter sq ft* 0	0.2	-
3	Landscaping visible to passersby from adjacent public right of way or public open spaces		*enter sq ft* 0	0.1	-
4	Landscaping in food cultivation		*enter sq ft* 0	0.1	-
				Green Factor numerator =	-

***** Do not count public rights-of-way in parcel size calculation.***

***** You may count landscape improvements in rights-of-way contiguous with the parcel. All landscaping on private and public property must comply with the Landscape Standards Director's Rule (DR 6-2009)***

Appendix D: Stockholm Biotope Area Factor Score Sheet

SURFACE:	FACTOR:	NUMBER:	AREA:	FACTOR * AREA:
Sub-factors greenery				
Unsupported ground greenery	2.0	-	0	0
Plant bed (>800 mm)	1.2	-	0	0
Plant bed (600-800 mm)	0.4	-	0	0
Plant bed (200-600 mm)	0.2	-	0	0
Green roof (> 300 mm)	0.4	-	0	0
Green roof (50 - 300 mm)	0.1	-	0	0
Greenery on walls	0.4	-	0	0
Balcony boxes	0.3	-	0	0
Supplementary factors greenery/biodiversity				
Diversity in the field layer	0.7	-	0	0
Natural species selection	0.5	-	0	0
Diversity on thin sedum roofs	0.1	-	0	0
Integrated balcony boxes with climbing plants	0.3	-	0	0
Butterfly restaurants	1.0	-	0	0
Bushes, general	0.2	-	0	0
Berry bushes	0.4	-	0	0
Large trees (trunk >30 cm)	2.4	0	0	0
Medium large trees (trunk 20-30 cm)	1.5	0	0	0
Small trees (trunk 16-20 cm)	1.0	0	0	0
Oak (Quercus robur)	3.0	0	0	0
Fruit trees	0.4	0	0	0
Fauna depots	2.0	0	0	0
Beetle feeders	2.0	0	0	0
Bird feeders	2	0	0	0
Supplementary factors greenery/recreation and social value				
Grass area usable for ball games and playing	1.2	-	0	0
Gardening areas in yards	0.5	-	0	0
Balconies and terraces prepared for growing	0.5	-	0	0
Shared roof terraces	0.2	-	0	0
Visible green roofs	0.1	-	0	0
Floral arrangements	0.2	-	0	0
Experiential value of bushes	0.1	-	0	0
Berry bushes with edible fruit, etc.	0.2	-	0	0
Trees, experiential value	0.5	0	0	0
Fruit trees and blooming trees	0.2	0	0	0
Pergolas, paths surrounded by leaves and other greenery	0.3	-	0	0
Bird feeders, experiential value	0.2	0	0	0
Supplementary factors greenery/climate - heat islands				
Trees with leafy shade over play areas, etc.	0.5	0	0	0
Pergolas, green corridors etc = shade from leaf cover	0.5	-	0	0
Green roofs, ground greenery - evening out of temp.	0.1	-	0	0
Sub-factors water				
Water surface, permanent	1.0	-	0	0
get through	0.3	-	0	0
Gravel and sand	0.2	-	0	0
Concrete slabs with joints	0.05	-	0	0

Appendix D: Stockholm continued

Supplementary factors water/biodiversity				
Biologically accessible permanent water	4.0	-	0	0
Dry areas with plants that temporarily fill with rainwater	2.0	-	0	0
Delay of rainwater in ponds etc.	0.2	-	0	0
Delay of rainwater in underground percolation systems	0.1	-	0	0
Runoff from impermeable surfaces to surfaces with plants	0.1	-	0	0
Supplementary factors water/recreational and social values				
Water surfaces	1.0	-	0	0
Biologically accessible water - experiential value	1.0	-	0	0
Fountains, circulations systems, etc.	0.3	0	0	0
Supplementary factors water/climate - heat islands				
Water collection during dry periods	0.5	-	0	0
Collected rainwater for watering - climate impact	0.05	-	0	0
Fountains etc. - cooling effect	0.3	0	0	0
Total (eco-effective area):				0
Total land area			0	
Achieved factor:				**0.00**
Balance sheet:	**Max amount:**	**Amount achieved:**	**:**	
B = Biodiversity	**30**			
S = Social value	**27**			
K = Climate adaptation	**18**			

Appendix E: Washington D.C. Green Area Ratio Score Sheet

Green Area Ratio Scoresheet

Address

Other / BZA Order

Lot size *(enter this value first)* *

Ward	Lot	Square	Zoning District

enter sq ft of lot: 0

multipli

SCORE: #DIV/0!

Landscape Elements

		Square Ft.		Factor	Total
A	**Landscaped areas (select one of the following for each area)**				
1	Landscaped areas with a soil depth of less than 24"		*enter sq ft* 0	0.3	-
2	Landscaped areas with a soil depth of 24" or greater		*enter sq ft* 0	0.6	-
3	Bioretention facilities		*enter sq ft* 0	0.4	-
B	**Plantings (credit for plants in landscaped areas from Section A)**				
1	Groundcovers, or other plants less than 2' tall at maturity		*enter sq ft* 0	0.2	-
2	Plants, not including grasses, 2' or taller at maturity - calculated at 9 sq ft per plant (typically planted no closer than 18" on center)	*enter number of plants* 0	0	0.3	-
3	Tree canopy for all trees 2.5" to 6" diameter or equivalent - calculated at 50 sq ft per tree	*enter number of trees* 0	0	0.5	-
4	Tree canopy for new trees 6" diameter or larger or equivalent - calculated at 250 sq ft per tree	*enter number of trees* 0	0	0.6	-
5	Tree canopy for preservation of existing tree 6" to 12" diameter or larger or equivalent - calculated at 250 sq ft per tree	*enter number of trees* 0	0	0.7	-
6	Tree canopy for preservation of existing tree 12" to 18" diameter or larger or equivalent - calculated at 600 sq ft per tree	*enter number of trees* 0	0	0.7	-
7	Tree canopy for preservation of all existing trees 18" to 24" dia. or equivalent - calculated at 1300 sq ft per tree	*enter number of trees* 0	0	0.7	-
8	Tree canopy for preservation of all existing trees 24" diameter or larger or equivalent - calculated at 2000 sq ft per tree	*enter number of trees* 0	0	0.8	-
9	Vegetated wall, plantings on a vertical surface		*enter sq ft* 0	0.6	-

Appendix E: Washington D.C. continued

C	**Vegetated or "green" roofs**			
		enter sq ft		
1	Over at least 2" and less than 8" of growth medium	0	0.6	-
		enter sq ft		
2	Over at least 8" of growth medium	0	0.8	-
D	**Permeable Paving*** **			
		enter sq ft		
1	Permeable paving over at least 6" and less than 24" of soil or gravel	0	0.4	-
		enter sq ft		
2	Permeable paving over at least 24" of soil or gravel	0	0.5	-
E	**Other**			
		enter sq ft		
1	Enhanced tree growth systems***	0	0.4	-
		enter sq ft		
2	Renewable energy generation	0	0.5	-
		enter sq ft		
3	Approved water features	0	0.2	-
	sub-total of sq ft =	*0*		
H	**Bonuses**			
		enter sq ft		
1	Native plant species	0	0.1	-
		enter sq ft		
2	Landscaping in food cultivation	0	0.1	-
		enter sq ft		
3	Harvested stormwater irrigation	0	0.1	-
			Green Area Ratio numerator =	-

****** Permeable paving and structural soil together may not qualify for more than one third of the Green Area Ratio score.***

Total square footage of all permeable paving and enhanced tree growth -

ECONorthwest
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DATE: February 15, 2017
TO: Austin City Staff
FROM: Heather Venhaus, Regenerative Environmental Design
Amy Belaire, PhD
Ed MacMullan and Sarah Reich, ECONorthwest
SUBJECT: RESULTS OF TASK 7E—TECHNICAL AND ECONOMIC ANALYSIS OF LANDSCAPE ELEMENTS

1 Introduction

This analysis focuses on six landscape elements that provide ecosystem services in urban landscapes: trees, green roofs, bioretention systems, vegetated walls, porous pavements, and cisterns. We evaluate these landscape elements for their *technical performance* (i.e., biophysical benefits) and associated *economic costs/benefits*.

For the technical review of biophysical benefits, we relied on the results of the literature review (Task 7B) and additional studies on each landscape element. We summarized peer-reviewed literature and local reports for the Austin area whenever possible; we also included additional studies conducted in locations with climates similar to Austin's (humid subtropical) when they were available. In cases where little published research exists, we relied on best available data regardless of location or climate. Technical performance was categorized into several key ecosystem service types prioritized by the City of Austin: (1) microclimate regulation and mitigation of urban heat island effects, (2) carbon storage and sequestration, (3) air pollutant removal, (4) stormwater retention and runoff reduction, (5) water filtration, and (6) biodiversity benefits. In addition, benefits to human well-being are summarized where data are available. Under each of these ecosystem service types, the relevant literature was summarized to provide an estimate of the range of likely benefits. We reviewed studies of performance for individual landscape elements in the field and lab as well as modeling studies that evaluated potential performance if landscape elements were broadly applied across an urban landscape. In the review below, results for biophysical performance are summarized on a per-unit or per-area basis, and, where modeling studies are available, results are reported for implementation at broader spatial scales. Although different studies often report different metrics for performance, we attempted to identify and report common metrics whenever possible to allow for comparison between different landscape elements.

The economic analysis of the costs and benefits of landscape elements also relied on the results of the literature review (Task 7B) and interviews with City of Austin staff. Our analysis also identified the factors that influence the magnitude of economic benefits. The degree to which we were able to quantify economic benefits varied by landscape element. For some landscape elements and some benefits, data were available to identify per-unit values specific to the City of Austin. In some cases, per-unit values were not available for the City of Austin, but were available for other, similar geographies or as a national average. In cases where data on per-unit economic values were not available, we described the value qualitatively, focusing on the mechanism of economic effect, direction and magnitude of change, and other factors that may influence the value. We estimated costs similarly, relying on primary estimates from the City of Austin's experience installing and maintaining the landscape elements where possible. If data were not available from the City of Austin, we relied on cost estimates from the literature. All dollar values are reported in 2015 equivalent dollars.

We summarize the results of the analysis by landscape element below. First we describe the results of the technical analysis, then follow with the results of the economic analysis.

2 Trees

2.1 Technical Analysis

Trees are known to provide a variety of ecosystem services in urban landscapes, including: (1) regulating microclimate and mitigating urban heat island effects, (2) sequestering and storing carbon, (3) capturing air pollutants, (4) intercepting rainwater to reduce stormwater runoff volumes, and (5) providing resources for urban biodiversity. Most of these benefits are correlated with the leaf area of the trees; larger trees and those with greater leaf area provide greater benefits than smaller trees or trees with less leaf area. Therefore, existing trees most likely provide more ecosystem services than newly planted trees. The range of benefits that trees would likely provide in the Austin urban ecosystem are summarized from relevant peer-reviewed literature and reports in Table 1 below.

Table 1. Range of Estimated Biophysical Benefits for Trees in Austin, Texas

Ecosystem Service Type	Range of Estimated Biophysical Benefits in Austin, Texas	References
Microclimate regulation and mitigation of urban heat island effects	2.2-7.0° F reduction in surface air temperatures (for areas underneath and adjacent to street tree canopy)	Loughner et al. 2012, Shashua-Bar et al. 2009, Davis et al. 2016, and Wang & Akbari 2016
Carbon storage and sequestration	Storage: 7.7-28.9 kg C/m^2 Sequestration (on a per-tree basis): 11-64 kg C/year for small trees[1]; 93-305 kg C/year for larger trees; average 0.28 kg C/m^2 tree cover per year	Nowak et al. 2013, Nowak & Dywer 2007, Davies et al. 2011, Nowak et al. 2016, iTree Design v 6.0
Air pollutant removal	6.6–12.0 g of air pollutants removed per m^2 of tree canopy, depending on location, size and type of tree On a per-tree basis: 2.0-13.3 g CO per tree, 12.2-63.4 g NO_2 per tree, 56.0-93.3 g O_3 per tree, 23.4-83.3 g PM_{10} per tree, and 7.1-34.6 g SO_2 per tree	Nowak & Dywer 2007 (including per-tree calculations derived from Tables 1 and 2)
Stormwater retention and runoff reduction	On a per-tree basis: 11-44 ft^3/year for small trees; 113-400 ft^3/year for large trees At broader scales: canopy coverage of 30% could reduce existing runoff volume by 12-13%	iTree Design v 6.0, Mullaney et al. 2015, Livesley et al. 2014, Sanders 1986
Water filtration	Can lead to reduced total pollutant loads due to some reduction of runoff volume.	
Biodiversity	Increased biodiversity observed in areas of greater tree coverage	Ikin et al. 2012, Strohbach et al. 2013, Belaire et al. 2014
Human well-being	Potential contribution to noise reduction, reduced crime, improved road safety, and other social benefits	Gomez-Baggethun et al. 2013, Kuo & Sullivan 2001, Tarran 2009

2.2 Economic Analysis

2.2.1 Economic Benefits

The economic benefits of ecosystem services provided by trees can depend on several site-specific factors. These include:

- The type and size of tree will influence the supply of ecosystem services and related economic benefits.
- The location of the tree onsite will influence benefits associated with energy use and cooling.
- The height of adjacent buildings will influence the extent to which street trees impact energy use and cooling demands.
- Access and visibility of trees influences property values and human well-being benefits.

Table 2 shows the estimated values of the economic benefits we identified for street trees.

[1] Small trees defined as 2-5 inch diameter live oak or elm species

Table 2. Range of Estimated Values of Economic Benefits of Street Trees in Austin, Texas

Economic Benefit	Range of Values of Economic Benefits for Austin, Texas	References
Energy Costs	Site-specific, depending on location of trees relative to building, baseline energy demand, and energy costs.	
Carbon Sequestration	$44-$239 per metric ton of Carbon	Interagency Working Group 2016
Nitrogen Dioxide Removal	$0.13-$0.33 per kg	Nowak et al. 2016
Sulfur Dioxide Removal	$0.04-$0.09 per kg	Nowak et al. 2016
Small Particulate Matter	$26.45-$66.14 per kg	Nowak et al. 2016
Avoided Stormwater Runoff Costs to City of Austin	$2 per cubic foot of stormwater diverted from system	American Forests 2002
Impacts on Property Values	Up to 13-19% increase for single-family residential. Higher rents; Longer leaseholder retention and lower turnover for commercial and multi-family rentals.	Wolf 2007, Martin Maggio and Appel 1989, Donovan and Butry 2011
Avoided Costs of Ecological and Species Habitat Management	Unquantifiable, but likely positive. Higher value for positive effects on habitat for sensitive species	
Avoided Health Care Costs, Improved Human Well-being	Unquantifiable, but positive relationships have been measured at a national scale, attributing benefits of access to green space to reduced healthcare costs and improved quality of life arising from improved newborn health; reduced incidence of ADHD; improved school performance; reduced crime; and improved cardiovascular health.	Wolf 2015

Economic Costs

The cost of street trees includes planting, pruning and maintenance. The total cost of a street tree during its life will vary depending on factors such as species, placement relative to other infrastructure, and climate. Costs vary geographically based on climate and prevalence of pests and diseases. Regional surveys of tree costs as reported by urban arborists and municipal foresters in the Piedmont (North Carolina to Texas) and Interior West (Texas west) are reported in Table 3. Austin sits on the border of these regions, so it would likely would experience costs somewhere within this range.

Depending on where street trees are located on a site they may or may not incur opportunity costs[2] for developers of occupying land that would otherwise be taken up by a building. For example, planting trees within required sidewalk right-of-ways many not incur opportunity costs for developers. Extensive plantings of trees on interior parts of the site may lessen developable area and potentially result in opportunity costs for the developer.

[2] Opportunity cost means the benefit or profit from one option that must be given up to achieve something else. In this context, the opportunity cost of installing required stormwater controls on land that otherwise would have been developed is the benefit (e.g., profit or rent) that could have been enjoyed from the development.

Table 3. Costs of Street Trees

	Piedmont Region[1]	Interior West Region
Planting (One-time)	$587	$97-$457
Pruning (Per tree per year, depending on size and age)	$0.07-$5.50	$4-$515
Pest and Disease Control (Per tree per year)	$23	N/A
Irrigation (Per year for first 5 years)	N/A	$1.14-$4.57
Removal (One-time, per inch of diameter)	$41-$260	$25-$40

Source: [1] Vargas et al. 2007; [2] McPherson et al. 2006.

3 Green Roofs

3.1 Technical Analysis

Green roofs, which can be either intensive or extensive in design, provide an option to increase vegetation cover in urban landscapes, compensating for the plants and soils that were removed during construction. The primary biophysical benefits of green roofs provide include: (1) regulating temperature and mitigating urban heat island effects, (2) sequestering and storing carbon, (3) retaining stormwater and reducing runoff volume, and (4) providing habitat and enhancing connectivity for biodiversity. In addition, there is some evidence that green roofs can capture and filter pollutants from water and air. The biophysical benefits that green roofs could likely provide in Austin are summarized from relevant peer-reviewed literature in Table 4 below.

Table 4. Range of Estimated Biophysical Benefits for Green Roofs in Austin, Texas

Ecosystem Service Type	Range of Estimated Biophysical Benefits in Austin, Texas	References
Microclimate regulation and mitigation of urban heat island effects	On a per-roof basis: maximum temperature reduction of 45-54° F for roof surface temperatures (compared to non-vegetated roofs) At broader scales: 1.6-5.4° F reduction in ambient air temperatures with widespread green roof implementation	Alexandri & Jones 2008, Susca et al. 2011, Santamouris 2014, Meek et al. 2014
Carbon storage and sequestration	Storage: 0-67.7 kg C/m^2 depending on plant type, substrate, and age of roof	Getter et al. 2009, Whittinghill et al. 2014
Air pollutant removal	Per unit area: 85 kg of pollutants removed per hectare of green roof per year (8.5 g/m^2), with 0.65-1.01 g SO_2/m^2, 2.33-3.57 g NO_2/m^2, 1.12-2.16 g PM_{10}/m^2, 4.49-7.17 g O_3/m^2 At broader scales: Up to 2046 metric tons of pollutants removed per year for widespread green roof implementation	Yang et al. 2008, Currie et al. 2008
Stormwater retention and runoff reduction	On a per-roof basis: 44-88% of rainfall volume retained per storm and 43-78% of rainfall volume retained annually At broader scales: 15-45% reduction in runoff volumes with widespread implementation	Carter et al. 2007, Simmons et al. 2013, Glass 2007, Berndtsson et al. 2010, Harper et al. 2015, Morgan et al. 2013, Meek et al. 2014
Water filtration	Mixed results for water quality. Although total concentrations may be higher in effluent, the total loads are lower due to high runoff volume retention.	Rowe et al. 2011, Ahiablame et al. 2012
Biodiversity	Green roofs can provide habitat for a relatively high diversity of invertebrate species, including native pollinators, and increase functional connectivity for these species	Colla et al. 2009, Tonietto et al. 2011, Madre et al. 2013, Braaker et al. 2014
Human well-being	Potential to reduce noise pollution and provide green views to building occupants	Van Renterghem & Botteldooren 2009, Oberndorfer 2007

3.2 Economic Analysis

3.2.1 Economic Benefits

The economic benefits of ecosystem services provided by green roofs can depend on several site-specific factors. These include:

- The type of green roof, intensive or extensive. Intensive roofs have thicker growing medium and can support more complex vegetation types that also provide more ecosystem service values compared with an extensive roof. Extensive roofs have less growing medium and can typically support less complex vegetation types, relative to an intensive roof.
- The number of floors in a building influences the impacts of heating and cooling benefits of a green roof on total energy use. Typically, heating and cooling benefits are limited to one or two floors directly beneath the green roof.
- The extent to which green roofs are visible from adjacent structures, and are accessible to building occupants, will increase the amenity benefits of the roof.

Table 5 shows the estimated values of the economic benefits we identified for green roofs.

Table 5. Range of Estimated Values of Economic Benefits of Green Roofs in Austin, Texas

Economic Benefit	Range of Values of Economic Benefits for Austin, Texas	References
Building Cost Savings	May extend the life of the roof underlayment by 20 years or more.	EPA 2000
Development Cost Savings	Developers may use green roofs to meet certain development requirements or earn a density bonus credit.	City of Austin No Date
Energy Savings	Expected reduction in energy demand and cost. Magnitude dependent on existing energy efficiency of the building and properties of the green roof. Buildings that are already well-insulated likely will experience more limited energy benefits. Energy savings are greatest for the first floor below the roof, with decreasing benefits up to four stories below the roof.	Blackhurst et al. 2010
Carbon Sequestration	$44-$239 per metric ton of Carbon	Interagency Working Group 2016
Nitrogen Dioxide Removal	$0.13-$0.33 per kg	Nowak et al. 2016
Small Particulate Matter	$0.04-$0.09 per kg	Nowak et al. 2016
Avoided Stormwater Runoff Costs to City of Austin	$2 per cubic foot of stormwater diverted from system	American Forests 2002
Avoided Stormwater Runoff Fee Assessed to Property Owners	Up to a 72% reduction in the monthly drainage charge assessed by the City of Austin. Actual savings depends on site-specific factors.	
Impacts on Property Values	Up to 6% increase in rental rates, which may increase property values	GSA 2011
Avoided Costs of Ecological and Species Habitat Management	Unquantifiable, but likely positive. Higher value for positive effects on habitat for sensitive species	
Avoided Health Care Costs, Improved Human Well-being	Unquantifiable, but likely positive if green roof is within view or accessible. Positive relationships have been measured at a national scale, attributing benefits of access to green space to reduced healthcare costs and improved quality of life arising from improved newborn health; reduced incidence of ADHD; improved school performance; reduced crime; and improved cardiovascular health.	Wolf 2015

3.2.2 Economic Costs

The type of green roof—extensive or intensive—influences both the installation costs as well as the maintenance costs. Table 6 shows the range of costs associated with green roofs. Because green roofs do not occupy space that would otherwise be taken up by site developments, they do not cause opportunity costs for developers.

Table 6. Costs of Green Roofs

	Construction Costs/Sq. Ft.[1]		Annual Maintenance Costs/Sq. Ft.[2]	
	Low	High	Low	High
Extensive	$7.38	$342.55	$0.02	$0.40
Intensive	$16.86	$550.19	$0.02	$0.40

Source: [1] Grey et al. 2013; [2] Center for Neighborhood Technology, No Date.

4 Bioretention, Biofiltration Systems, and Rain Gardens

4.1 Technical Analysis

The terms bioretention cells, rain gardens, and biofiltration systems describe small depressions that retain stormwater and promote infiltration/filtration via vegetated systems. They are designed to function similarly to natural systems and typically provide the following ecosystem services: (1) retaining stormwater and reducing runoff volumes, (2) filtering pollutants from stormwater, and (3) providing habitat for biodiversity and potentially supporting enhanced ecological conditions in nearby streams. In addition, these types of landscape elements can provide some carbon storage and sequestration services as well as minor cooling effects. The range of biophysical benefits that rain gardens, bioretention, and biofiltration systems could likely provide in Austin are summarized from peer-reviewed literature and local reports in Table 7.

Table 7. Range of Estimated Biophysical Benefits for Bioretention, Biofiltration Systems, and Rain Gardens in Austin, Texas

Ecosystem Service Type	Range of Estimated Biophysical Benefits in Austin, Texas	References
Microclimate regulation and mitigation of urban heat island effects	Some potential for minor cooling effects (as with any small vegetated area)	Perring et al. 2016, Davis et al. 2016
Carbon storage and sequestration	Storage: 0-3.34 kg C/m^2 Sequestration: 0.05-0.09 kg C/m^2 per year	Bouchard et al. 2013, Davies et al. 2011
Air pollutant removal	No estimates in literature; however, the cooling effects of vegetation can contribute to reduced ozone formation	Perring et al. 2013
Stormwater retention and runoff reduction	On a per-site basis: 40-100% of rainfall volume retained per storm and 58-97% of rainfall volume retained annually. At broader spatial scales: Substantial reduction in runoff volumes and peak flow with widespread implementation	DeBusk & Wynn 2011, Li et al. 2009, Brown et al. 2013, Jennings 2016, Geosyntec 2016, Glick et al. 2016, Hunt et al. 2008
Water filtration	Concentration reduction: significant reduction in total suspended solids (mg/L) likely (85-95% removal) Pollutant load reduction: 30-50% reduction in load for total suspended solids, total phosphorus, total nitrogen, fecal coliform, and total zinc with widespread implementation (conservative estimate)	Geosyntec 2016, International BMP Database 2014, Richter et al. 2015, Limouzin et al. 2011
Biodiversity	Bioretention systems and rain gardens support similar or greater diversity of invertebrates than nearby green spaces. With widespread implementation, they can also contribute to improved ecological health and aquatic life in urban streams.	Kazemi et al. 2009, Kazemi et al. 2011, Glick et al. 2016, Hamel et al. 2013, Walsh et al. 2015
Human well-being	Some potential to provide residents with increased exposure to nature and associated health benefits (as with other vegetated areas)	Sandifer et al. 2015

4.2 Economic Analysis

4.2.1 Economic Benefits

The economic benefits of ecosystem services provided by bioretention, biofiltration systems and rain gardens can depend on a number of site-specific factors. These include:

- The extent of area covered by these landscape factors influences the supply of ecosystem service values.
- The vegetation mix will influence the supply of ecosystem service values.

Table 8 shows the estimated values of the economic benefits we identified for bioretention, biofiltration systems and rain gardens.

Table 8. Range of Estimated Values of Economic Benefits of Bioretention, Biofiltration Systems, and Rain Gardens in Austin, Texas

Economic Benefit	Range of Values of Economic Benefits for Austin, Texas	References
Energy Costs	Unlikely to have significant effect; however, installations with trees, water features, or in areas with considerable influence on a building may generate minor energy cost savings, especially if density of installations is high in an otherwise hardscape-dominated area.	
Carbon Sequestration	$44-$239 per metric ton of Carbon	Interagency Working Group 2016
Avoided Stormwater Runoff Costs to City of Austin	$2 per cubic foot of stormwater diverted from system	American Forests 2002
Avoided Stormwater Runoff Fee Assessed to Property Owners	Up to a 72% reduction in the monthly drainage charge assessed by the City of Austin. Actual savings depends on site-specific factors.	
Impacts on Property and Amenity Values	Evidence of increase in property value is limited, with some studies showing potential negative effect and others positive. Expected benefit associated with well-maintained installations that add curb appeal beyond typical landscaping.	
Avoided Costs of Ecological and Species Habitat Management	Unquantifiable, but likely positive. Higher value for positive effects on habitat for sensitive species	
Avoided Health Care Costs, Improved Human Well-being	Unquantifiable, but positive relationships have been measured at a national scale, attributing benefits of access to green space to reduced healthcare costs and improved quality of life arising from improved newborn health; reduced incidence of ADHD; improved school performance; reduced crime; and improved cardiovascular health.	Wolf 2015

4.2.2 Economic Costs

Costs of implementing bioretention and rain garden stormwater controls can be very site specific depending on local soil, vegetation, and climate conditions. We report construction and operations and maintenance (O&M) costs below in Table 9. To the extent that bioretention, biofiltration systems and rain gardens reduce a site's developable space, they will generate opportunity costs for developers.

Table 9. Costs of Bioretention, Biofiltration Systems, and Rain Gardens

	Construction Costs/Cubic Foot[1]		Annual Maintenance Costs/Sq. Ft.[2]	
	Low	High	Low	High
Biofiltration, Construction Cost Per Cubic Foot of Water Quality Volume	\$5.14	\$18.05	\$0.38	\$0.747
Rain Garden, Construction Cost Per Cubic Foot of Water Quality Volume	\$8.21	\$61.79	\$0.38	\$0.747
Vegetative Filter Strip, Construction Cost Per Square Foot of Installation	\$1.98	\$4.80	\$0.38	\$0.747

Source: [1]City of Austin; [2] Center for Neighborhood Technology, No Date.

5 Vegetated Walls

5.1 Technical Analysis

Vertical surfaces that support vegetation are often called "green walls" or "green facades." This type of landscape element can take several different design forms, including direct green walls in which vegetation grows directly on a wall surface; "double-skin" designs that leave some air space between plants and building wall surface; and "living walls" that include encased growing medium within a support structure anchored to a wall surface. The primary benefits of vegetated walls relate to their role in microclimate regulation, but they may also provide additional ecosystem services such as capturing air pollutants, reducing noise levels, and providing resources for biodiversity. The biophysical benefits that vegetated walls could provide in Austin are summarized from peer-reviewed literature in Table 10 below.

Table 10. Range of Estimated Biophysical Benefits for Vegetated Walls in Austin, Texas

Ecosystem Service Type	Range of Estimated Biophysical Benefits in Austin, Texas	References
Microclimate regulation and mitigation of urban heat island effects	<u>On a per-wall basis</u>: maximum temperature reduction of 16-36° F for wall surface temperatures (compared to non-vegetated walls) <u>At broader scales</u>: 5.4-7.2° F reduction in ambient air temperatures with widespread vegetated wall implementation	Alexandri & Jones 2008, Mazzali et al. 2013, Perez et al. 2011, Cameron et al. 2014, Chen et al. 2013
Carbon storage and sequestration	Likely storage of < 1.0 kg C/m^2 for non-woody vegetation and 6.7 – 16.03 kg C/ m^2 for woody vegetation	Davies et al. 2011
Air pollutant removal	<u>At broad scales</u>: Up to 3,300 kg pollutants removed per year (and concentration reductions of 6-62% possible) with widespread implementation. Annual removal estimates per pollutant include 620 kg NO_2, 1090 kg O_3, 1370 kg PM_{10}, and 230 kg SO_2.	Currie et al. 2008, Pugh et al. 2012
Stormwater retention and runoff reduction	No estimates in the literature; very little contribution to stormwater retention expected	
Water filtration	No estimates in the literature; very little benefit to water filtration expected	
Biodiversity	Vegetated walls can provide some resources for invertebrates and urban birds	Madre et al. 2015, Chiquet et al. 2013
Human well-being	Can reduce noise pollution, provide sound insulation for buildings, and provide green views to residents	Azkorra et al. 2015

5.2 Economic Analysis

5.2.1 Economic Benefits

The economic benefits of ecosystem services provided by vegetated walls or green facades can depend on a number of site-specific factors. These include:

- The type of vegetated wall, direct type with vegetation rooted in the soil at ground level, or living-wall type, with escalating growing medium up the wall.
- The aspect the wall faces, with more energy-demand effects for plantings on south and west facing sides.
- The height of the building. Buildings with many stories will likely see less cooling benefits as a percentage of total cooling costs relative to buildings with fewer stories.
- The area of coverage, with greater extent of vegetation providing more benefits.

Table 11 shows the estimated values of the economic benefits we identified for bioretention, biofiltration systems and rain gardens.

Table 11. Range of Estimated Values of Economic Benefits of Vegetated Walls in Austin, Texas

Economic Benefit	Range of Values of Economic Benefits for Austin, Texas	References
Building Cost Savings	Depends on façade material, but may reduce maintenance requirements and extend the life of the building façade.	Perini 2013
Energy Costs	Expected reduction in energy demand and cost, largely dependent on existing insulation quality. Buildings that are already well-insulated likely will experience more limited energy benefits.	Hassan 2015
Carbon Sequestration	\$44-\$239 per metric ton of Carbon	Interagency Working Group 2016
Nitrogen Dioxide Removal	\$0.13-\$0.33 per kg	Nowak et al. 2016
Sulfur Dioxide Removal	\$0.04-\$0.09 per kg	Nowak et al. 2016
Small Particulate Matter	\$26.45-\$66.14 per kg	American Forests 2002
Impacts on Property and Amenity Values	Likely positive, for the same reason green roofs and street trees provide benefits. May affect the value of the building it's installed on, as well as adjacent buildings with views of the green façade.	
Avoided Costs of Ecological and Species Habitat Management	Unquantifiable, but likely insignificant, because habitat provided by vegetated walls is typically not suitable for sensitive species, and does not offer habitat types that are considered scarce, even in an urban environment.	
Avoided Health Care Costs, Improved Human Well-being	Unquantifiable, but positive relationships have been measured at a national scale, attributing benefits of access to green space to reduced healthcare costs and improved quality of life arising from improved newborn health; reduced incidence of ADHD; improved school performance; reduced crime; and improved cardiovascular health.	Wolf 2015

5.2.2 Economic Costs

Green wall systems vary in installation costs, depending on their design. Livings walls are typically more expensive to install and maintain than green façades using ground-level plantings. Given their close proximity to buildings, it is unlikely that most vegetated walls or green façade projects would limit site development and so would not cause opportunity costs for developers. Table 12 includes construction and maintenance costs for vegetated walls.

Table 12. Costs of Vegetated Walls

	Construction Costs/Sq. Ft.		Annual Maintenance Costs/Sq. Ft.	
	Low	High	Low	High
Living Walls	$80	$150	$7	$15
Green Facades	$25	$40	$0.25	$1

Sources: Liang 2014, Architek No Date; State of Victoria 2014; Perini and Rosasco 2013

6 Porous Pavement

6.1 Technical Analysis

Porous pavement systems retain stormwater, allowing it to permeate the surface layer and infiltrate into underlying substrate. Several different types of porous pavement systems exist, some of which allow vegetation to grow between paving units. The biophysical benefits of porous pavement are centered on runoff reduction and filtration of water pollutants. In addition, this landscape element may also contribute to urban landscape temperature regulation and provide some benefits to biodiversity. The biophysical benefits that porous pavements could likely provide in Austin are summarized from peer-reviewed literature and local reports in Table 13 below.

Table 13. Range of Estimated Biophysical Benefits for Porous Pavement in Austin, Texas

Ecosystem Service Type	Range of Estimated Biophysical Benefits in Austin, Texas	References
Microclimate regulation and mitigation of urban heat island effects	Mixed results for cooling capabilities of porous pavements in similar climates, although new-generation materials appear to have greater thermal performance.	Santamouris 2013, Qin 2015, Kevern et al. 2009, Stempihar et al. 2013
Carbon storage and sequestration	No estimates in the literature; very little carbon storage and sequestration expected	
Air pollutant removal	Unlikely to have air quality benefits; however, cooling effects could reduce formation of ozone	
Stormwater retention and runoff reduction	On a per-site basis: 74-100% of rainfall volume retained per storm At broader spatial scales: Some reduction in runoff volumes and peak flow	Collins et al. 2008, Dreelin et al. 2006, Hunt et al. 2008, Ball and Rankin 2010, Geosyntec 2016
Water filtration	Concentration reduction: significant reduction in total suspended solids (58-94%), metals (20-99%), and total phosphorus (10-78%) (mg/L) likely Pollutant load reduction: Total pollutant loads are likely low due to high runoff volume retention. 3.4 kg/ha/year estimated for total nitrogen and 0.4 kg/ha/year estimated for total phosphorus in one study (Bean et al. 2007)	International Stormwater BMP Database 2014, Richter et al. 2015, Ahiablame et al. 2012, Bean et al. 2007
Biodiversity	With widespread implementation, they can contribute to increased groundwater recharge and improved ecological health and aquatic life in urban streams.	

6.2 Economic Analysis

6.2.1 Economic Benefits

The economic benefits of ecosystem services provided by porous pavement depend primarily on the extent of site coverage. Porous pavement generates economic benefits primarily through the stormwater retention effect, reducing the need for other types of stormwater infrastructure, or reducing the risk of economic costs associated with flooding events.

Table 14. Range of Estimated Values of Economic Benefits of Porous Pavement in Austin, Texas

Economic Benefit	Range of Values of Economic Benefits for Austin, Texas	References
Building Cost Savings	May reduce cost of private stormwater management infrastructure required, such as curbs and gutters and catchment basins.	Century West Engineering No Date
Avoided Stormwater Runoff Costs to City of Austin	$2 per cubic foot of stormwater diverted from system	American Forests 2002
Avoided Stormwater Runoff Fee Assessed to Property Owners	Up to a 72% reduction in the monthly drainage charge assessed by the City of Austin. Actual savings depends on site-specific factors, and demonstration that installation meets design criteria.	
Avoided Costs of Ecological and Species Habitat Management	Unquantifiable, but likely positive. Higher value for positive effects on habitat for sensitive species	

6.2.2 Economic Costs

The cost of porous pavement varies depending on the system used. We list cost ranges for construction and O&M in Table 15. Porous pavement is usually used instead of a conventional pavement system wherever hardscape is required in a development. For this reason, it is unlikely to generate opportunity costs for developers, and may increase the overall developable space because traditional curbs and gutters and stormwater management ponds are not required.

Table 15. Costs of Porous Pavement

	Construction Costs/Sq. Ft.[1]		Annual Maintenance Costs/Sq. Ft.	
	Low	High	Low	High
Porous Pavement	$6.34	$18.55	$0.01	$0.23

Source: [1] City of Austin; [2] Center for Neighborhood Technology, No Date.

7 Cisterns

7.1 Technical Analysis

Cisterns are above- or below-ground tanks that retain and store rainwater for reuse. Although they are not a vegetation- or soil-based landscape element, they do provide biophysical benefits in urban systems and can reduce potable water usage for landscape irrigation needs. Their primary benefits center on stormwater retention. Several researchers highlight stormwater harvesting via cisterns as a critical complement to infiltration-based techniques (e.g., rain gardens) to achieve urban stormwater management goals and improve urban stream ecology. The benefits of cisterns for Austin are summarized from peer-reviewed literature and local reports in Table 16 below.

Table 16. Range of Estimated Biophysical Benefits for Cisterns in Austin, Texas

Ecosystem Service Type	Range of Estimated Biophysical Benefits in Austin, Texas	References
Microclimate regulation and mitigation of urban heat island effects	Unlikely to contribute to microclimate regulation or urban heat island effects	
Carbon storage and sequestration	Unlikely to contribute to carbon storage and sequestration; however, water reuse is associated with reduced carbon emissions	
Air pollutant removal	Unlikely to have air quality benefits; however, water reuse is associated with reduced emissions at power plants	
Stormwater retention and runoff reduction	Some reduction in runoff volumes and peak flow with widespread implementation	Geosyntec 2016, Glick et al. 2016
Water filtration	Can lead to reduced total pollutant loads due to high runoff volume retention.	
Biodiversity	With widespread implementation, they can reduce erosive events and peak flow, which can in turn lead to improved ecological health and aquatic life in urban streams.	Geosyntec 2016, Glick et al. 2016, Walsh et al. 2015

7.2 Economic Analysis

7.2.1 Economic Benefits

The economic benefits of ecosystem services provided by cisterns and rainwater harvesting depend on the following factors.

- Size of system and the volume of stormwater captured.
- The type of system. “Smart” systems empty out after a rain event so that they have capacity for the next storm system.
- Types of water re-use supported. Systems that capture and release stormwater provide fewer benefits than those that use captured rainwater for on-site applications.

Table 17. Range of Estimated Values of Economic Benefits of Cisterns in Austin, Texas

Economic Benefit	Range of Values of Economic Benefits for Austin, Texas	References
Reduced Water Purchases and Use of Potable Water	Reusing harvested rainwater onsite can reduce use of potable water and offset water purchased from other sources.	
Increased Water Reliability	During times of shortage, cisterns can reduce the timing and duration of water shortages by augmenting primary water supplies.	
Avoided Stormwater Runoff Costs to City of Austin	$2 per cubic foot of stormwater diverted from system	American Forests 2002
Avoided Stormwater Runoff Fee Assessed to Property Owners	Site-specific, depending on percent reduction in impervious area.	
Avoided Costs of Ecological and Species Habitat Management	Unquantifiable, but likely positive. Higher value for positive effects on habitat for sensitive species	

7.2.2 Economic Costs

Cisterns and rain barrel systems vary in installation costs, depending on their design. To the extent that installing cisterns and rain barrels takes up space that would otherwise be occupied by development, they generate opportunity costs for developers. Cisterns installed below ground may not generate opportunity costs, depending on development demands for below ground space.

Table 18. Costs of Cisterns

	Construction Costs/Cubic Foot[1]		Annual Maintenance Costs/Installation[2]	
	Low	High	Low	High
Cistern Construction Cost Per Cubic Foot of Water Quality Volume	$24.68	$59.84	$350	$

Sources: [1]City of Austin, [2] Kim 2011 and City of Austin

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DATE: May 8, 2017
TO: Austin City Staff
FROM: Amy Belaire, PhD, Ed MacMullan, ECONorthwest, and Heather Venhaus, Regenerative Environmental Design
SUBJECT: Draft Task 7H – Determining the Value of Landscape Elements

I. INTRODUCTION

Functional Green is an environmental planning tool that aims to integrate nature and ecosystem services into new built environments. Ecosystem services are defined as "the benefits people obtain from ecosystems," such as clean air and water, carbon storage and sequestration, and microclimate regulation (Millennium Ecosystem Assessment 2005). To aid in the development of Functional Green, the consultant team has conducted a thorough literature review and analysis of the ecosystem services and economic benefits and costs associated with a range of landscape elements that can be incorporated into dense urban areas. These landscape elements include trees (both existing and newly planted), green roofs, vegetated walls, planting beds, cisterns, porous pavements, and rain gardens.

The review and analysis that has been conducted provides an in-depth understanding of each landscape element's likely performance – in both biophysical and economic terms – in the Austin ecosystem. This information provides a solid analytical foundation for the scoring of landscape elements based on their performance, which in turn facilitates developing a performance-based weighted rating for each element. With this approach, the City of Austin provides a landscape rating process based on science, transparency, and analytical rigor.

The primary goal of this report is to provide recommendations on preliminary ratings for the landscape elements that will likely be included in Functional Green. In the sections below, we describe the biophysical and economic criteria that informed the evaluation of landscape elements and provide details about the Multi-Criteria Decision Analysis process we used to calculate the preliminary ratings. It is important to recognize that this is the first step in a multi-step process; developing the final landscape element ratings will involve working through a series of case studies in which the ratings can be implemented and tested for development projects in Austin. The results of the case studies will inform future modifications to the preliminary ratings for the landscape elements.

II. OVERVIEW OF METHODS FOR CALCULATING LANDSCAPE ELEMENT RATINGS

To determine the preliminary ratings for the landscape elements, the consultant team used a Multi-Criteria Decision Analysis (MCDA)[1] approach. The decision-making analysis framework is commonly used to structure and solve problems dealing with multiple and diverse criteria. The primary steps in our approach include the following:

- STEP 1: Determine a score for each landscape element based on its ecological and economic performance. These scores indicate the performance of each

[1] For a recently published discussion on MCDA for ecosystem services valuation, please see: Saarikoski, H.,

landscape element relative to the others. Scores were assigned to each landscape element based on its performance in nine different biophysical and economic criteria. In other words, each landscape element received nine performance scores, one for each of the criteria evaluated.

- STEP 2: Assign a weighted value to each of the nine biophysical and economic criteria for which the landscape elements were evaluated. The objective of this step is to represent a diverse range of preferences with respect to ecosystem services and economic outcomes. We refer to these as the criteria weights and evaluated several different weighting scenarios.
- STEP 3: Multiply the performance scores by the criteria weights to arrive at adjusted scores, and sum across all criteria to get a final score for the landscape elements. We refer to these results as the preliminary ratings for the landscape elements.

At this time, the ratings for the landscape elements are represented with symbols rather than numeric values. This is because numeric values are somewhat meaningless until target scores are identified for the parcels using Functional Green. We also recognize that the ratings will likely be adjusted at a later date after case studies are conducted, at which point numeric values will be more applicable.

III. STEP 1: DETERMINE THE BIOPHYSICAL AND ECONOMIC PERFORMANCE SCORES OF EACH LANDSCAPE ELEMENT

Criteria for performance evaluation

The analysis included nine primary criteria to evaluate each landscape element that the Functional Green program will likely include[2]. Six criteria are ecosystem services that the City of Austin identified as high priorities. An additional three criteria have significance to property development and use. The six ecosystem services are:

1. Microclimate regulation and mitigation of urban heat island effects
2. Carbon storage and sequestration
3. Air pollutant removal
4. Stormwater retention and runoff reduction
5. Water filtration
6. Biodiversity benefits

In addition to these ecosystem services, several additional criteria were included in the analysis to reflect property development and use considerations. Landscape elements in highly developed environments can improve human health and well-being. For example, views of and access to green spaces (e.g., green roofs) can help reduce stress and improve mental productivity. In addition, the economics literature describes the beneficial impacts that landscape elements can have on property values. To the extent that property markets perceive a landscape element as an amenity, increased demand and sale prices will reflect this. Lastly, landscape elements can also occupy space that would otherwise be developed. This can have implications for the financial returns to developers. Therefore, the three property development and use considerations in Functional Green are:

7. Human health and well-being
8. Effects on property values
9. Effects on developable area

[2] See summary memos for Tasks 7B and 7E for more information on these criteria.

Scoring landscape element performance

The performance scores for each of the criteria above were informed by work conducted under Tasks 7B and 7E, which summarized peer-reviewed literature and local reports for the Austin area. The consultants also included additional studies conducted in locations with climates similar to Austin's (humid subtropical) when they were available. In cases where little published research exists, consultants relied on best available data regardless of location or climate. Common metrics were used whenever possible to assess performance and allow for comparisons between the different landscape elements.

The landscape elements were scored against each other in terms of their expected relative performance for each of the nine criteria listed above. In the ratings, the consultants used a scoring system in which "A" means that the element is expected to perform well (in the top 20%) in comparison to the other elements evaluated. "B" means the performance of this element is in the mid-range when compared to the other elements evaluated (in the range of 50-70% performance). "C" means this element is on the low end of benefits when compared to the other elements evaluated (in the range of 20-40%), and "D" was assigned when minimal or no benefits were expected. In addition, a +/- was used as needed to differentiate between landscape elements in terms of their performance. The performance scores for the nine criteria are summarized in Table 1 below (additional details about the scores are included in Appendix A.)

Table 1. Scores for landscape elements based on their relative performance with respect to nine criteria. See Appendix A for more details about the scores.

	Criteria for evaluating the landscape elements								
	1. Microclimate regulation	2. Carbon storage & sequestration	3. Air pollutant removal	4. Stormwater retention	5. Water filtration	6. Biodiversity benefits	7. Property value	8. Human well-being	9. Developable area
Existing tree	A	A	A	B+	C+	A	A	A	C
Newly planted tree	B	B	B	C+	C	B	B+	A-	B
Green roof	A-	B	B+	A	B	A	A-	B	A+
Rain garden	C+	C+	C	A	A	A	B	B	B
Vegetated wall	B+	C+	B	D	D	C	B	B	A+
Planting beds	C+	C	C	C	C-	C+	C	B	B
Porous pavement	C	D	D	A	A	D	C	D	A
Cistern	D	C-	C-	A	C	D	C	D	C+

A = high performance, in 80-100% range
B = mid-range performance, in 50-70% range
C = low performance, in 20-40% range
D = very low performance, in the bottom 1%

IV. STEP 2: ASSIGN WEIGHTED VALUES TO THE CRITERIA AND MULTIPLY BY PERFORMANCE SCORES

After the landscape elements were scored based on their relative performance in each of the nine criteria, the consultants evaluated different scenarios in which the criteria were assigned weighted values according to a range of possible preferences (under the constraint that the weights must sum to 1). The weighted values assigned to the nine criteria under the different scenarios are summarized in Table 2. The four scenarios include the following:

- **Scenario 1** - All nine criteria have equal weight.
- **Scenario 2** - The six ecosystem services were given higher weight than the three development and use considerations. This scenario represents a preference for landscape elements that provide strong ecosystem services with less weight given to economic constraints.
- **Scenario 3** - The three development and use considerations were given higher weight than the six ecosystem services. This scenario represents a preference for landscape elements that provide strong development and use benefits with less weight given to ecosystem services.
- **Scenario 4** - The nine criteria were assigned weights according to the number and scale of stakeholders affected.

Table 2. Weighted values for the nine criteria by which the landscape elements were evaluated. Four different scenarios were used to represent a range of possible preferences.

Criteria for evaluating the landscape elements	Scenario 1 Values	Scenario 2 Values	Scenario 3 Values	Scenario 4 Values
1. Microclimate regulation	0.11	0.16	0.06	0.15
2. Carbon storage and sequestration	0.11	0.16	0.06	0.10
3. Air pollutant removal	0.11	0.16	0.06	0.15
4. Stormwater retention	0.11	0.10	0.06	0.15
5. Water filtration	0.11	0.10	0.06	0.10
6. Biodiversity benefits	0.11	0.16	0.06	0.15
7. Property values	0.11	0.05	0.22	0.05
8. Human health & well-being	0.11	0.05	0.21	0.10
9. Developable area	0.11	0.05	0.21	0.05
TOTAL (weights are constrained to sum to 1 in each scenario)	1.00	1.00	1.00	1.00

For each of the four scenarios described above, the performance scores (Table 1) were multiplied by the values of the weighted criteria (Table 2) to arrive at adjusted scores.

V. STEP 3: SUM ACROSS ALL CRITERIA TO CALCULATE PRELIMINARY RATINGS FOR LANDSCAPE ELEMENTS

After we calculated adjusted scores in Step 2, we summed across all criteria. This resulted in preliminary ratings for each landscape element. We use a rating system of 1-5 stars in Table 3 below to illustrate the preliminary ratings under each scenario we tested. The right-most column in Table 3 shows the average rating across all four scenarios.

Table 3. Preliminary ratings for landscape elements across four weighted scenarios

Landscape elements	Scenario 1 Rating	Scenario 2 Rating	Scenario 3 Rating	Scenario 4 Rating	AVERAGE RATING
Existing tree	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
Newly planted tree	★★★	★★★	★★★★	★★★	★★★
Green roof	★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
Rain garden	★★★★	★★★	★★★★	★★★★	★★★★
Vegetated wall	★★	★★	★★★	★★	★★
Planting beds	★	★	★★	★	★
Porous pavement	★	★	★	★	★
Cistern	★	★	★	★	★

The preliminary ratings for each landscape element stayed relatively consistent, regardless of the scenario. This suggests that the ratings shift very little, even when a broad variety of preferences are taken into account with respect to ecosystem services and economic considerations.

VI. BONUS POINTS

In addition to the eight landscape elements, the consultants envision options for bonus points, which will provide additional points above those of already-credited landscape elements in the Functional Green tool. All bonus points would be rated equally and would have a low rating (one star). Potential bonus point options include:

- Native plants
- Pollinator gardens
- Low water use landscapes
- Alternative water use landscapes

APPENDIX A

Table A: Microclimate regulation and mitigation of urban heat island effects

Landscape elements	Microclimate perfomance (biophysical)	Microclimate perfomance (economic)	Score
Exising tree	2.2-7.0° F reduction in surface air temperatures for areas underneath and adjacent to street tree canopy	Reduced energy costs.	A
Newly planted tree	Smaller canopy area results in less shade and transpiration than larger existing trees	Reduced energy costs. Benefits start at close to zero and increase over time.	B
Green roof	1.6-5.4° F reduction in ambient air temperatures with widespread green roofs; 45-54° F reduction in roof surface temperatures	Reduced energy costs.	A-
Raingarden	Some potential for minor cooling effects (as with any small vegetated area).	Installations with trees, water features, or in areas with considerable influence on a building may generate minor energy savings.	C+
Vegetated wall	5.4-7.2° F reduction in ambient air temperatures with widespread green walls; 16-36° F reduction in wall surface temperatures.	Expected reduction in energy demand and cost, largely dependent on existing insulation quality. Building that are already well-insulated likely will experience more limited energy benefits.	B+
Planting beds or boxes	Some potential for minor cooling effects (as with any small vegetated area)	Estimated to have minimal benefits.	C+
Porous paving	Mixed results for cooling capabilities of porous pavements in similar climates, although new-generation materials appear to have greater thermal performance.	Minimal economic benefits.	C
Cistern	Unlikely to contribute to microclimate regulation or urban heat island effects.	Minimal economic benefits.	D

Table B: Carbon storage & sequestration

	Carbon storage & sequestration (biophysical)	Carbon storage & sequestration (economic)	Score
Existing tree	Storage: 7.7 - 28.9 kg C/m^2 tree cover Sequestration: 93 - 305 kg C/year for larger trees	$44-$239/metric ton of carbon stored or sequestered	A
Newly planted tree	Storage: 7.7 - 28.9 kg C/m^2 tree cover Sequestration: 11 - 64 kg C/year for small trees	Same as above but benefits will start at close to zero and increase over time.	B
Green roof	Storage: 0 - 67.7 kg C/m^2 depending on plant type, substrate, and age of roof.	$44-$239/metric ton of carbon stored or sequestered	B
Rain garden	Storage: 0 - 3.34 kg C/m^2 Sequestration: 0.05-0.09 kg C/m^2 per year	$44-$239/metric ton of carbon stored or sequestered	C+
Vegetated wall	Storage: < 1.0 kg C/m^2 for non-woody and 6.7 – 16.0 kg C/ m^2 for woody vegetation.	$44-$239/metric ton of carbon stored or sequestered	C+
Planting beds or boxes	Estimated to be less than a newly planted tree	Estimated to be less than a newly planted tree	C
Porous paving	No estimates in the literature; very little carbon storage and sequestration expected.	Minimal economic benefits.	D
Cistern	Unlikely to contribute to carbon storage and sequestration; however, water reuse is associated with reduced carbon emissions	Minimal economic benefits.	D

Table C: Air pollutant removal

	Air Quality (biophysical)	Air Quality (economic)	Score
Existing tree	Up to 12.0 g of air pollutants removed per m^2 of tree canopy, depending on location, size and type of tree	\$0.13-\$0.33/kg NO2 \$0.04-\$0.09/kg SO2 \$26.45-\$66.14/kg Particulate Matter	A
Newly planted tree	Smaller trees with reduced leaf area capture fewer air pollutants than larger trees	\$0.13-\$0.33/kg NO2 \$0.04-\$0.09/kg SO2 \$26.45-\$66.14/kg Particulate Matter but benefits will start at close to zero and increase over time.	B
Green roof	Up to 8.5 g of pollutants removed per m2 of green roof per year.	\$0.13-\$0.33/kg NO2 \$0.04-\$0.09/kg SO2 \$26.45-\$66.14/kg Particulate Matter	B+
Rain garden	No estimates in the literature; however, cooling effects of vegetation can lead to reduced ozone formation.	Minimal economic benefits.	C
Vegetated wall	Cooling effects can lead to reduced ozone formation; up to 3,300 kg pollutants removed per year with widespread green walls.	\$0.13-\$0.33/kg NO2 \$0.04-\$0.09/kg SO2 \$26.45-\$66.14/kg Particulate Matter	B
Planting beds or boxes		Minimal economic benefits.	C
Porous paving	Unlikely to have air quality benefits; however, cooling effects could reduce formation of ozone.	Minimal economic benefits.	D
Cistern	Unlikely to have air quality benefits; however, water reuse is associated with reduced emissions at power plants	Minimal economic benefits.	C-

Table D: Stormwater retention and runoff reduction

	Water retention (biophysical)	Water retention (economic)	Score
Existing tree	113-400 ft3/year for large trees	$2 per cubic foot of stormwater diverted from City of Austin stormwater infrastructure	B+
Newly planted tree	11-44 ft3/year for small trees	Benefits will start at close to zero and increase over time.	C+
Green roof	44-88% of rainfall volume retained per storm and 43-78% of rainfall volume retained annually per roof.	$2 per cubic foot of stormwater diverted from City of Austin stormwater infrastructure.	A
Rain garden	40-100% of rainfall volume retained per storm and 58-97% of rainfall volume retained annually per garden.	$2 per cubic foot of stormwater diverted from City of Austin stormwater infrastructure	A
Vegetated wall	No estimates in the literature; very little contribution to stormwater retention expected.	Minimal economic benefits	D
Planting beds or boxes	Estimated to be less than a newly planted tree.	Estimated to be less than a newly planted tree.	C
Porous paving	74-100% of rainfall volume retained per storm.	$2 per cubic foot of stormwater diverted from City of Austin stormwater infrastructure. Up to 72% reduction in monthly drainage charge.	A
Cistern	High stormwater retention possible with large capacity and “smart” systems.	$2 per cubic foot of stormwater diverted from City of Austin stormwater infrastructure. Up to 72% reduction in monthly drainage charge.	A

Table E: Water filtration

	Water filtration (biophysical)	Water filtration (economic)	Score
Existing tree	Tree canopy can lead to reduced total pollutant loads due to some reduction of runoff volume via canopy interception	$2 per cubic foot of stormwater diverted from City of Austin stormwater infrastructure	C+
Newly planted tree	Smaller trees with reduced canopy coverage will have reduced rainwater interception rates.	Same as above but benefits will start at close to zero and increase over time.	C
Green roof	Mixed results for water quality. Although total concentrations may be higher in effluent, the total loads are lower due to high runoff volume retention.	$2 per cubic foot of stormwater diverted from City of Austin stormwater infrastructure.	B
Rain garden	Reduced concentration of total suspended solids likely (85-95% removal).	$2 per cubic foot of stormwater diverted from City of Austin stormwater infrastructure.	A
Vegetated wall	No estimates in the literature; very little benefit to water quality expected.	Minimal economic benefits	D
Planting beds or boxes	Estimated to be equal to or less than newly planted tree	Minimal economic benefits	C-
Porous paving	Reduced concentrations of total suspended solids (58-94%), metals (20-99%), and total phosphorus (10-78%) likely.	$2 per cubic foot of stormwater diverted from City of Austin stormwater infrastructure. Up to 72% reduction in monthly drainage charge.	A
Cistern	No direct filtration, but some water quality benefits possible due to reduction in runoff volume.	Minimal economic benefits.	C

Table F: Biodiversity benefits

	Biodiversity (biophysical)	Biodiversity (economic)	Score
Existing tree	Increased biodiversity observed in areas of greater tree coverage.	Avoided costs of ecological and species habitat management or replacement.	A
Newly planted tree	Increased biodiversity observed in areas of greater tree coverage.	Avoided costs of ecological and species habitat management or replacement but benefits will start at close to zero and increase over time.	B
Green roof	Can provide habitat for diversity of invertebrates (including native pollinators) and increase functional connectivity.	Provides habitat for insect and bird species.	A
Rain garden	Can support diversity of invertebrates and contribute to improved stream health with widespread implementation.	Avoided costs of ecological and species habitat management or replacement.	A
Vegetated wall	Vegetated walls can provide some resources for invertebrates and urban birds.	Likely insignificant because habitat provided by vegetated walls is typically not suitable for sensitive species, and does not offer habitat types that are considered scarce, even in an urban environment.	C
Planting beds or boxes	Can provide habitat for invertebrates (including native pollinators).	Provides habitat for insect species.	C+
Porous paving	Limited research but improved ecological health and aquatic life in urban streams may occur with widespread implementation.	No economic benefits.	D
Cistern	Limited research but improved ecological health and aquatic life in urban streams may occur with widespread use.	No economic benefits.	D

Table G: Property Value

	Property Values (biophysical)	Property Values (economic)	Score
Existing tree	N/A	Up top 13%-19% increase for single-family residential. Higher rents; longer leaseholder retention and lower turnover for commercial and multi-family rentals.	A
Newly planted tree	N/A	Same as above but benefits will start at close to zero and increase over time.	B+
Green roof	N/A	Up to 6% increase in rental rates, which can increase property values for rental properties.	A-
Rain garden	N/A	Expected benefits associated with well maintained installations that add curb appeal beyond typical landscaping.	B
Vegetated wall	N/A	Likely positive, for the same reason green roofs and street trees provide benefits. May affect the value of the building it's installed on, as well as adjacent buildings with views of the green façade.	B
Planting beds or boxes	N/A	Minimal economic benefits.	C
Porous paving	N/A	Minimal economic benefits.	C
Cistern	N/A	Minimal economic benefits.	C

Table H: Human health and well-being

	Human Well-Being (biophysical)	Human Well-Being (economic)	Score
Existing tree	N/A	Positive relationship between access to greenspaces and reduced healthcare costs and improve quality of life.	A
Newly planted tree	N/A	Positive relationship between access to greenspaces and reduced healthcare costs and improve quality of life.	A-
Green roof	N/A	Positive relationship between access to greenspaces and reduced healthcare costs and improve quality of life.	B
Rain garden	N/A	Positive relationship between access to greenspaces and reduced healthcare costs and improve quality of life.	B
Vegetated wall	N/A	Positive relationship between access to greenspaces and reduced healthcare costs and improve quality of life.	B
Planting beds or boxes	N/A	Positive relationship between access to greenspaces and reduced healthcare costs and improve quality of life.	B
Porous paving	N/A	No economic benefits	D
Cistern	N/A	No economic benefits	D

Table I: Developable area

	Developable (biophysical)	Developable (economic)	Score
Existing tree	N/A	Trees take up space at ground level that could otherwise be occupied by developed site/building.	C
Newly planted tree	N/A	Trees take up space at ground level that could otherwise be occupied by developed site/building.	B
Green roof	N/A	No impact on developable area at ground level.	A+
Rain garden	N/A	Rain gardens take up developable space at ground level.	B
Vegetated wall	N/A	Little to no impact on developable area at ground level	A+
Planting beds or boxes	N/A	Planting beds take up space at the ground level that could otherwise be occupied by development.	B
Porous paving	N/A	Little to no impact on developable area at ground level.	A
Cistern	N/A	Cisterns take up space at ground level	C+