ID 1057: Methods for examining plant growth, substrate moisture content, and other variables on an experimental green roof in the Great Plains, USA

Lee R. Skabelund, BLA, MLA, ASLA, PLA
Associate Professor of Landscape Architecture
College of Architecture, Planning and Design
Kansas State University, Manhattan, Kansas

Collaborators include many faculty members & students from K-State (KSU) and beyond, including Jialin Liu of Southwest University in China, who worked with me for parts of 2018 and 2019 as a visiting scholar, and two students (Allyssa Decker and Priyasha Shrestha) partially funded by KSU's three-year Mary K. Jarvis Research Chair, which I was awarded in the fall of 2015.

http://www.k-state.edu/greenroofs/

APDESIGN
LANDSCAPE ARCHITECTURE AND REGIONAL & COMMUNITY PLANNING
THE COLLEGE of ARCHITECTURE, PLANNING & DESIGN // K-STATE

Presentation Purposes & Components:

This presentation highlights ways to collect data on a green roof to identify resilient plant species, measure vegetative cover for different mixes, assess thermal benefits & carbon sequestration, and explore the implications of specific green roof management practices.

This research has helped designers and scientists better understand the changes and dynamics of selected plant mixes and their abiotic environment over several years.

A 10-year study of experimental green roof (EGR) changes over time is envisioned.

Via interdisciplinary collaboration our team of 10 different disciplines seeks to improve GR design, installation & management—and the quality and range of ecosystem services.

Our undergraduate, MLA, PhD & faculty studies reveal the importance of different disciplinary perspectives in green roof research.

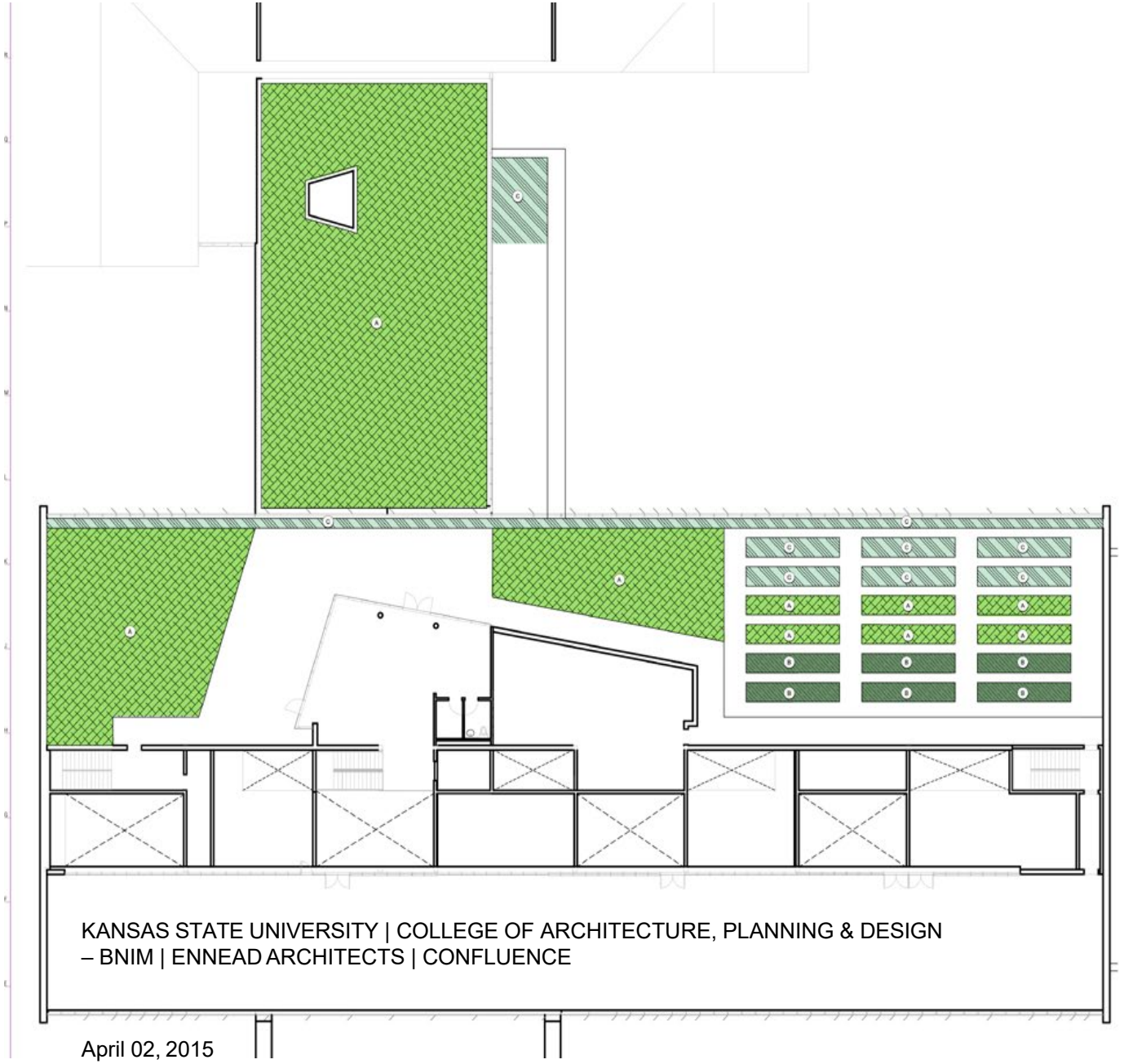
Primary Reference: Liu, J.L., Shrestha, P., Skabelund, L.R., Todd, T., Decker, A., and M.B. Kirkham. 2019. "Growth of prairie plants and sedums in different substrates on an experimental green roof in Mid-Continental USA." In *Science of the Total Environment*, Vol. 697. https://doi.org/10.1016/j.scitotenv.2019.134089

K-State Green Roof Context: The Flint Hills Ecoregion

The **soil along ridgelines** of the Flint Hills are **typically thin (comparable to green roof substrates in some instances)** especially in terms of the **harsh growing conditions** they induce on vegetation.

Two substrate types and three mixed-species plant mixes at three depths are being studied on the K-State APDesign Experimental Green roof.

KSU APDesign Green Roofs (April 2015 drawing & plant list by the design team)



GREEN ROOF PLANT SCHEDULE (THIS SHEET ONLY)

KEY	QTY.	BOTANICAL NAME	COMMON NAME	SIZE	ROOT	SPACING & REMARKS
		PERENNIALS / SEDUM				
		Dalea purpurea	PRAIRIE CLOVER	#1	CONT.	1'-0" TRIANGULAR SPACING
		Packera (senecio) obovata	PRAIRIE RAGWORT	#1	CONT.	1'-0" TRIANGULAR SPACING
		Sedum album f. murale	MURALE WHITE STONECROP	#1	CONT.	1'-0" TRIANGULAR SPACING
		Sedum ellacombeanum	RUSSIAN STONECROP	#1	CONT.	1'-0" TRIANGULAR SPACING
		Sedum hybridum 'Immergruenchen'	LITTLE EVERGREEN STONECROP	#1	CONT.	1'-0" TRIANGULAR SPACING
		Sedum kamtschaticum var. floriferum 'Weihenstephaner Gold'	ORANGE STONECROP	#1	CONT.	1'-0" TRIANGULAR SPACING
		Sedum lanceolatum	LANCELEAF STONECROP	#1	CONT.	1'-0" TRIANGULAR SPACING
		Sedum nuttallianum	YELLOW STONECROP	#1	CONT.	1'-0" TRIANGULAR SPACING
		Sedum sexangulare	TASTELESS STONECROP	#1	CONT.	1'-0" TRIANGULAR SPACING
		Sedum spurium 'Summer Glory'	DRAGONS BLOOD STONECROP	#1	CONT.	1'-0" TRIANGULAR SPACING
		GRASSES				
		Bouteloua curtipendula	SIDEOATS GRAMA	#1	CONT.	1'-0" TRIANGULAR SPACING
		Bouteloua dactyloides	BUFFALO GRASS	#1	CONT.	1'-0" TRIANGULAR SPACING
		Bouteloua gracilis	BLUE GRAMA	#1	CONT.	1'-0" TRIANGULAR SPACING
		Carex brevior	SHORTBREAK SEDGE	#1	CONT.	1'-0" TRIANGULAR SPACING
		Koeleria pyramidata	PRAIRIE JUNEGRASS	#1	CONT.	1'-0" TRIANGULAR SPACING
		Schizachyrium scoparium	LITTLE BLUESTEM	#1	CONT.	1'-0" TRIANGULAR SPACING
		Sporobolus heterolepis	PRAIRIE DROPSEED	#1	CONT.	1'-0" TRIANGULAR SPACING
	10,920	TOTAL SEDUMS + PERENNIALS + GRASSES				

PLANTING MIXES:

A MIX A: ALL SEDUM
Sedum album f. murale
Sedum ellacombeanum
Sedum hybridum 'Immergruenchen'
Sedum kamtschaticum var. floriferum 'Weihenstephaner Gold'
Sedum sexangulare
S. spurium 'Summer Glory'

B MIX B: NATIVE SEDUM AND GRASS MIX
Bouteloua curtipendula
Bouteloua dactyloides
Bouteloua gracilis
Schizachyrium scoparium
Sedum lanceolatum
Sedum nuttallianum

C MIX C: NATIVE GRASSES AND FORBS
Carex brevior
Dalea purpurea
Koeleria pyramidata
Packera (senecio) obovata
Schizachyrium scoparium
Sporobolus heterolepis

Final Plan for Substrates & Planting Mixes

4"

A	A	B	B
B	B	A	A
C	C	C	C
B	B	A	A
A	A	B	B
C	C	C	C

6"

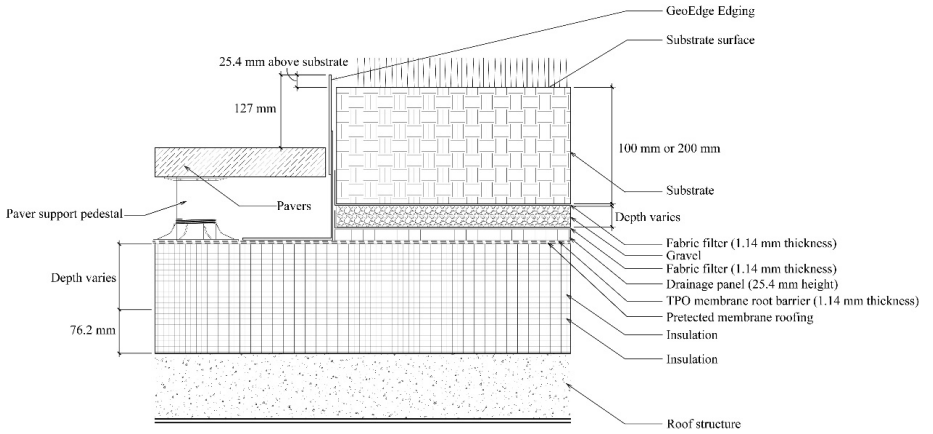
A	A	B	B
B	B	C	C
C	C	A	A
B	B	C	C
A	A	B	B
C	C	A	A

8"

A	A	B	B
B	B	A	A
C	C	C	C
B	B	A	A
C	C	C	C
A	A	B	B

Shaded cells = Kansas BuildEx substrate.
Non-shaded cells = Rooflite Extensive MC substrate.

A, B, and C represent plant mixes:
all *Sedum* (A);
Sedum & native grasses (B);
and all native grasses & forbs (C).



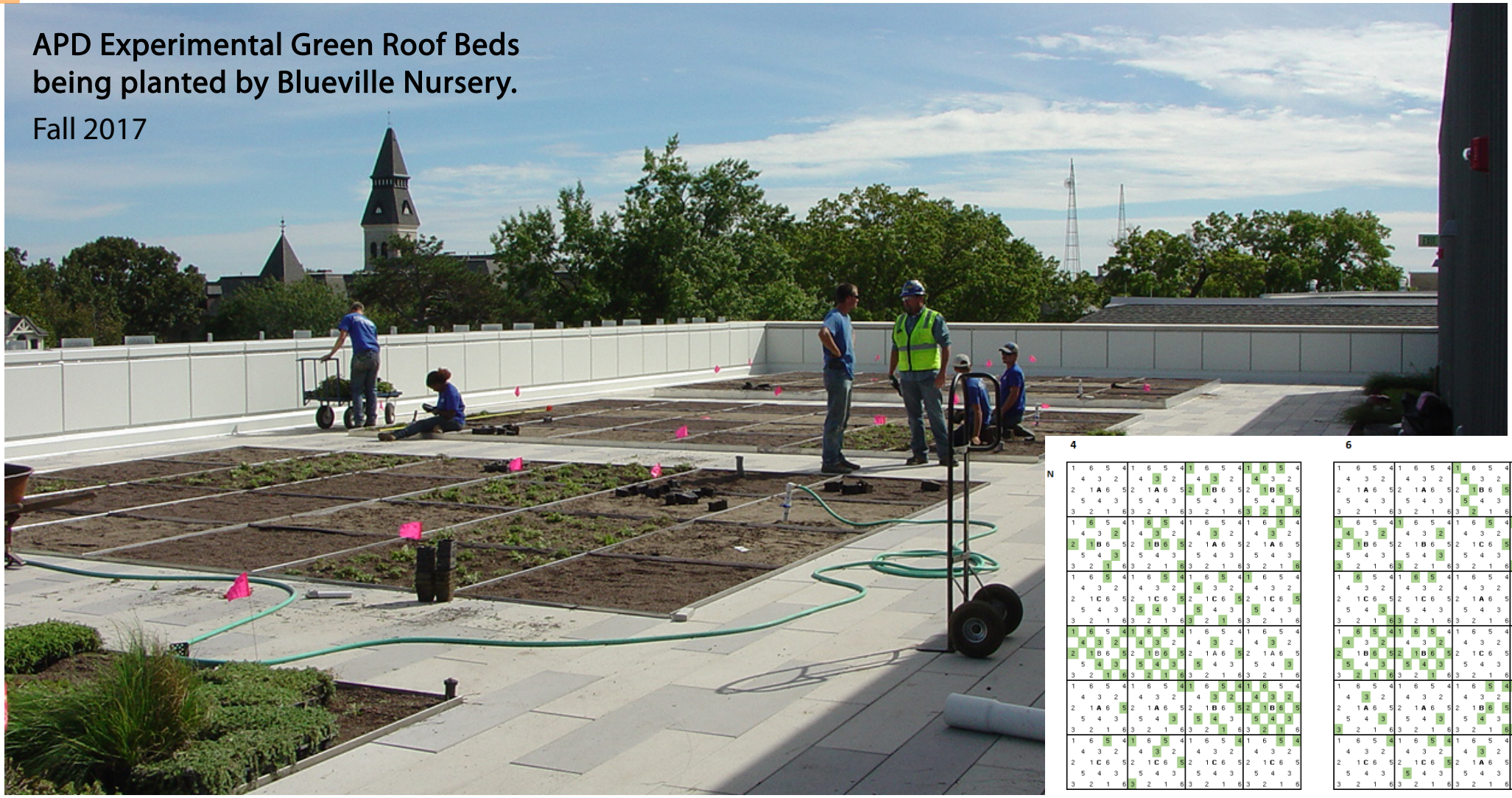
June-July 2017 construction photos

APDesign Experimental Green Roof Beds being installed by contractors working with green roof installers from Blueville Nursery.

Summer of 2017

APD Experimental Green Roof Beds being planted by Blueville Nursery.

Fall 2017



Some replanting was done by Blueville during the Fall of 2017, and quite a bit by our research team in May & June 2018. Plot sizes and substrate depths varied from the plans.

The numbers highlighted in green show the plants considered “dead” after the spring 2018 green roof audit. Our team asked that new plants be delivered so we could move our research forward in 2018.

APDesign Experimental Green Roof Plant Species for the three 6-Species Plant Mixes

Mix A: All Sedums	Mix B: Sedums and native grasses	Mix C: Native grasses and forbs
Sedum album var. murale	Bouteloua curtipendula	Carex brevoir
Sedum ellacombeanum	Bouteloua dactyloides	Dalea purpurea
Sedum hybridum	Bouteloua gracilis	Koeleria pyramidata
Sedum kamtschaticum var. floriferum	Schizachyrium scoparium	Packera obovata
Sedum sexangulare	Sedum reflexum	Schizachyrium scoparium
Sedum spurium	Sedum ruprestre	Sporobolus heterolepis

1		6		5		4
	4		3		2	
2		1		6		5
	5		4		3	
3		2		1		6

KSU-APDesign Green Roofs & Three Experimental GR Beds

The sandy BuildEx substrate shows up lighter on aerial imagery.

Particle Size (mm)	KS BuildEx	Rooflite
Clay < 0.002	2.9	1.3
Silt 0.002 - 0.0063	4.5	5.8
Sand 0.063 – 2.0	67.6	52.4
Gravel > 2.0	25	40.5

4"

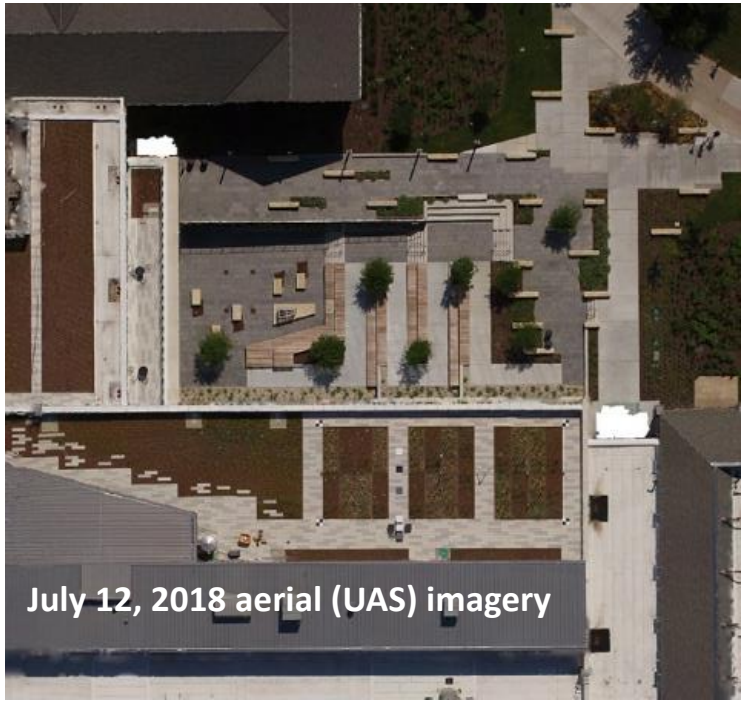
A	A	B	B
B	B	A	A
C	C	C	C
B	B	A	A
A	A	B	B
C	C	C	C

6"

A	A	B	B
B	B	C	C
C	C	A	A
B	B	C	C
A	A	B	B
C	C	A	A

8"

A	A	B	B
B	B	A	A
C	C	C	C
B	B	A	A
C	C	C	C
A	A	B	B



Shaded cells = Kansas BuildEx substrate.
Non-shaded cells = Rooflite Extensive MC substrate.

A, B, and C represent plant mixes:
all *Sedum* (A);
Sedum & native grasses (B);
and all native grasses & forbs (C).

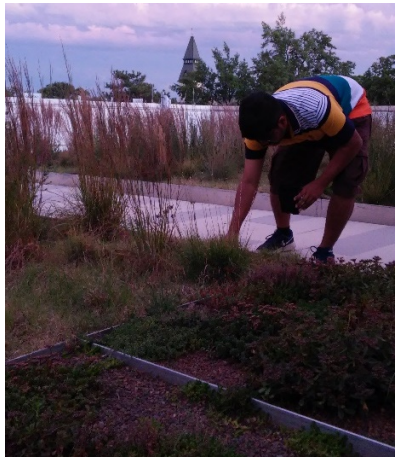
2017

2020

"The Jewell"

Designed as an all-sedum green roof, this roof was irrigated for part of one season and has hosted many ruderal plant species, and many were weeded by LRS and student volunteers to reduce the spread of seeds.

Removing weeds near the APD-EGR 11-12 Sep 2019
(ragweed, marestail, foxtail, crabgrass, spurge, etc.)



APD-EGR weeding by team members took a substantial amount of time in 2018 & 2019.

Many weed seeds came in with the potted live plants; some with the BuildEx substrate.

JARVIS Fellows & Visiting Scholar work on the APDesign-EGR

Instrumentation

Green roof monitoring

Data collection & analysis

Maintenance (mostly weeding)

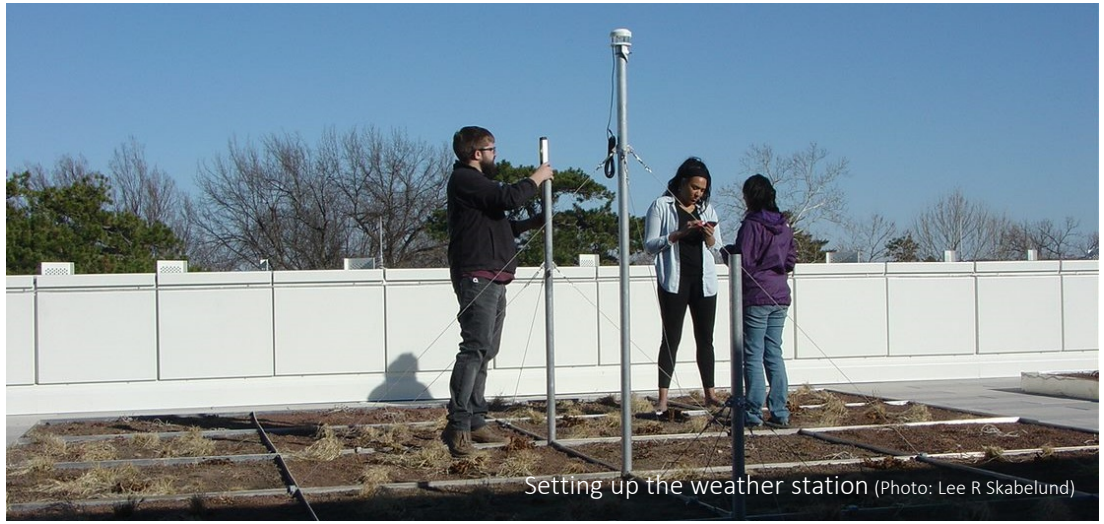
Conferences and outreach events

Memorial Stadium Green Roofs
(Lee Skabelund & Pam Blackmore plant & butterfly studies & plant management work, plus other monitoring work…)

Seaton Hall Green Roofs
(Lee's ongoing observations…)

APD Green Roof >>>


Sensor installation on the APD-EGR (Photo: Lee R Skabelund)


Setting up the weather station (Photo: Lee R Skabelund)


Data collection on the APD-EGR (Photo: Lee R Skabelund)

APD-EGR EXPERIMENTAL DESIGN

- 72 experimental plots/cells in total
  - 4-inch, 6-inch, and 8-inch substrate depths
  - 2 substrate types
  - 3 types of plant mixes
    - Sedum only
    - Sedum & native grasses
    - Native grasses & forbs
- Priyasha Shrestha's research focused on growth & health of 6 grass species and 1 sedge in Mixes B and C of the 4-inch substrate (which ranges in depth from 2.5-4")

  Mix B:
  - Bouteloua curtipendula (Sideoats grama)
  - Bouteloua dactyloides (Buffalograss)
  - Bouteloua gracilis (Blue grama)
  - Schizachyrium scoparium (Little bluestem)

  Mix C
  - Schizachyrium scoparium (Little bluestem)
  - Carex brevoir (Shortbeak sedge)
  - Koeleria pyramidata (Junegrass species)
  - Sporobolus heterolepis (Prairie dropseed)
- Focused on first growing season plant growth & health
- Kansas Buildex and Rooflite Extensive MC substrates

KA	RA	RB	KB
KB	RB	RA	KA
KC	RC	RC	KC
RB	KB	KA	RA
RA	KA	KB	RB
RC	KC	KC	RC

K = Kansas Build-ex Substrate

R = Rooflite Substrate

A = Sedum only mix

B = Sedum & native grasses mix

C = Native grasses & forbs mix

METHODS to document Plant Health measuring transpiration

1. Plant performance
2. Substrate performance

A. Survival

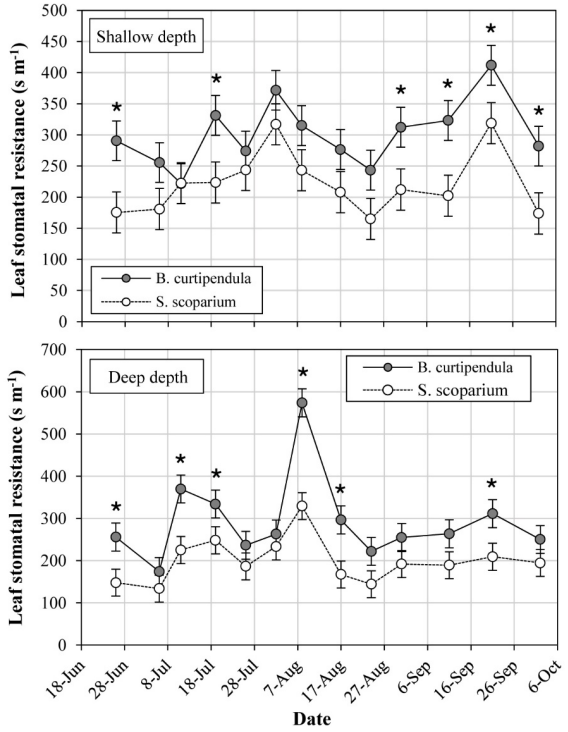
B. Growth
   a) Height
   b) Coverage
   c) Biomass

C. Plant health
   a) Stomatal resistance
   b) Visual assessment

Visual Assessment of Plant Health on a scale of 1 to 5

The graphs show leaf stomatal resistance for *B. curtipendula* (sideoats grama) and *S. scoparium* (little bluestem) over time in both profiles at the 4-inch (6.0-13.0 cm) and 8-inch (16.5-25.5 cm) depths.

Stomatal resistance measurement using leaf porometer



During the first growing season under the irrigation regime, these two grass species had low levels of drought stress. Stomatal resistance for both grass species ranged between 134 s m^{-1} to 574 s m^{-1}.

Under very stressful conditions, plant stomatal resistances are typically greater than 4000 s m^{-1} (Kirkham 1983).

METHODS to document Plant Growth measuring height & cover

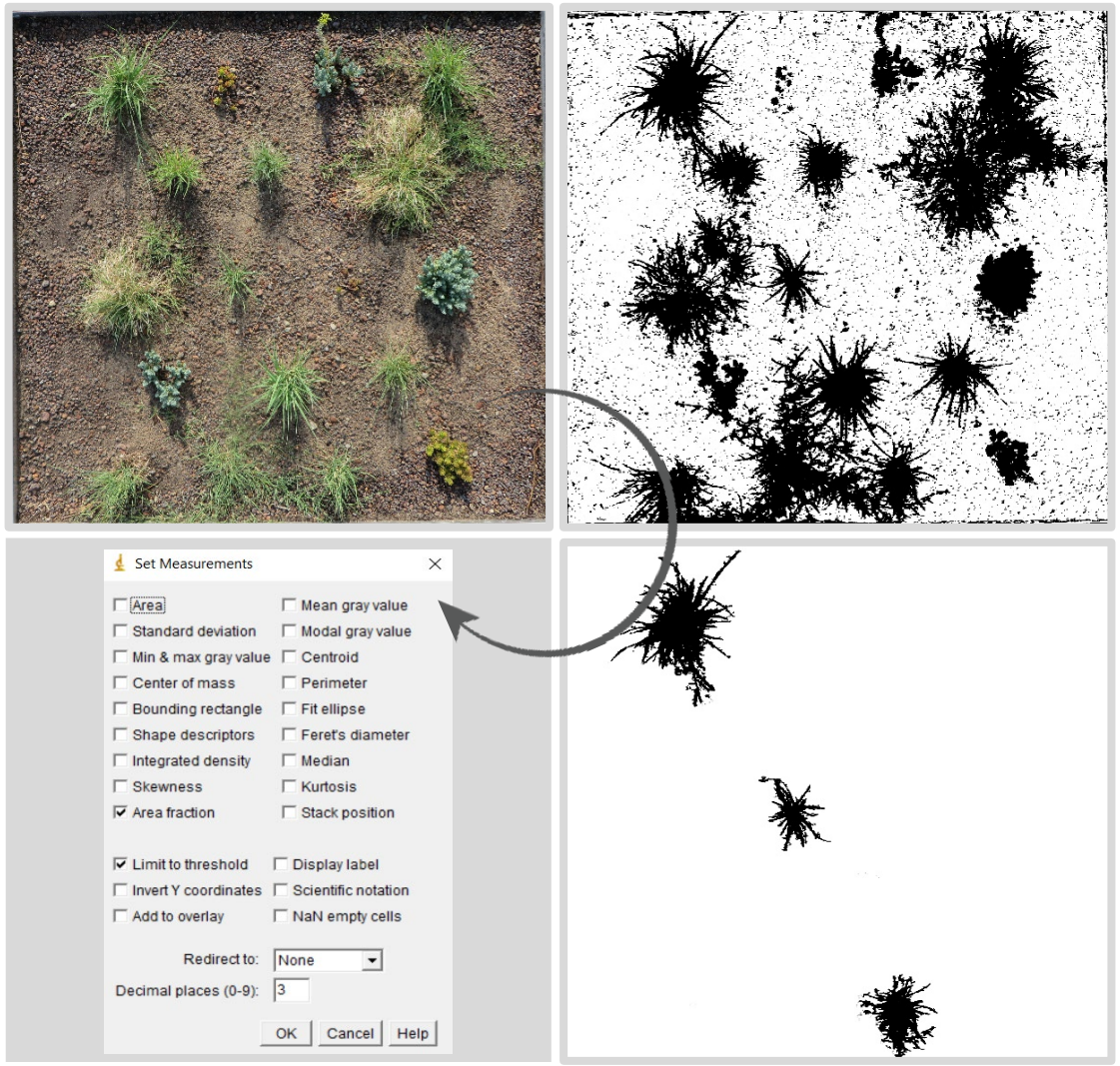
BC	SRu	SRe	SS
SS	BG	BD	
BD	BC	SRu	SRe
SRe	SS	BG	
BG	BD	BC	SRu

Mix B

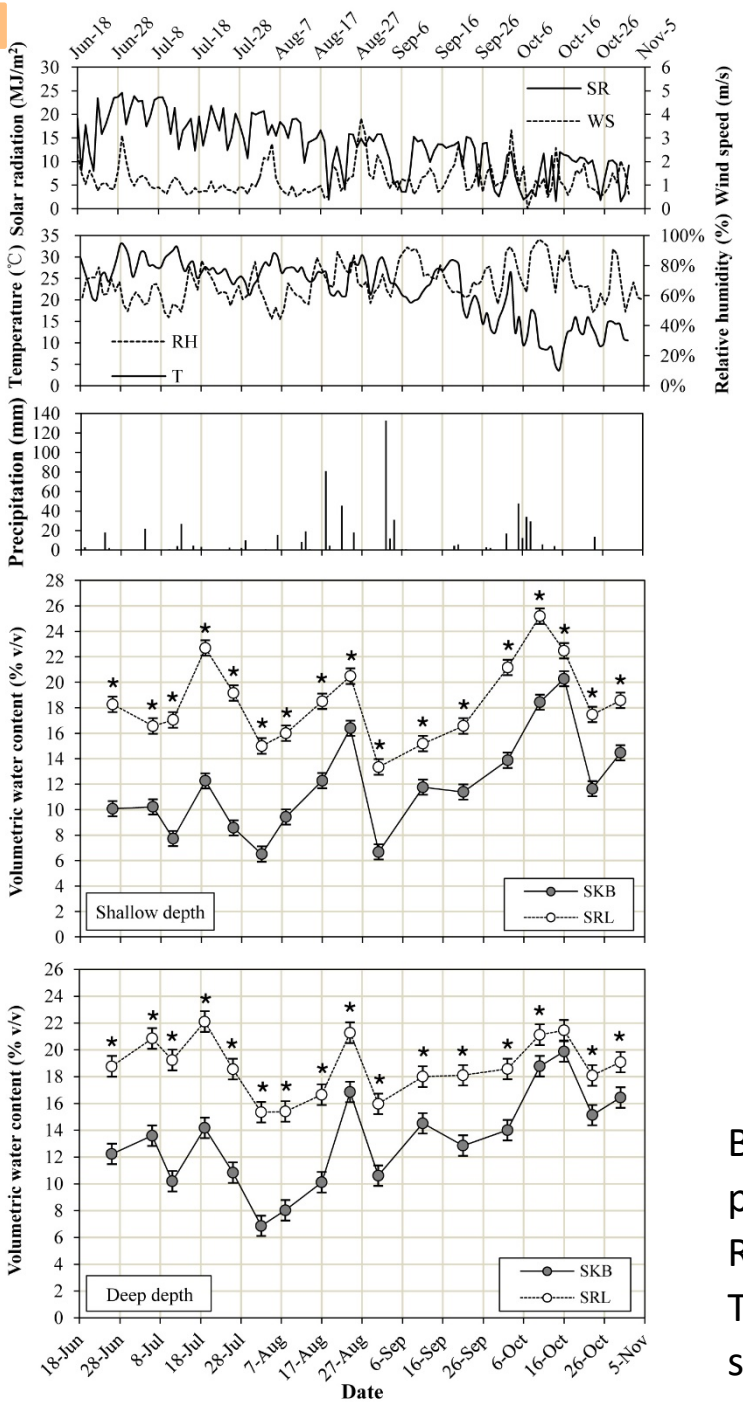
Priyasha's MLA thesis focused on 6 grasses planted in the 4-inch bed

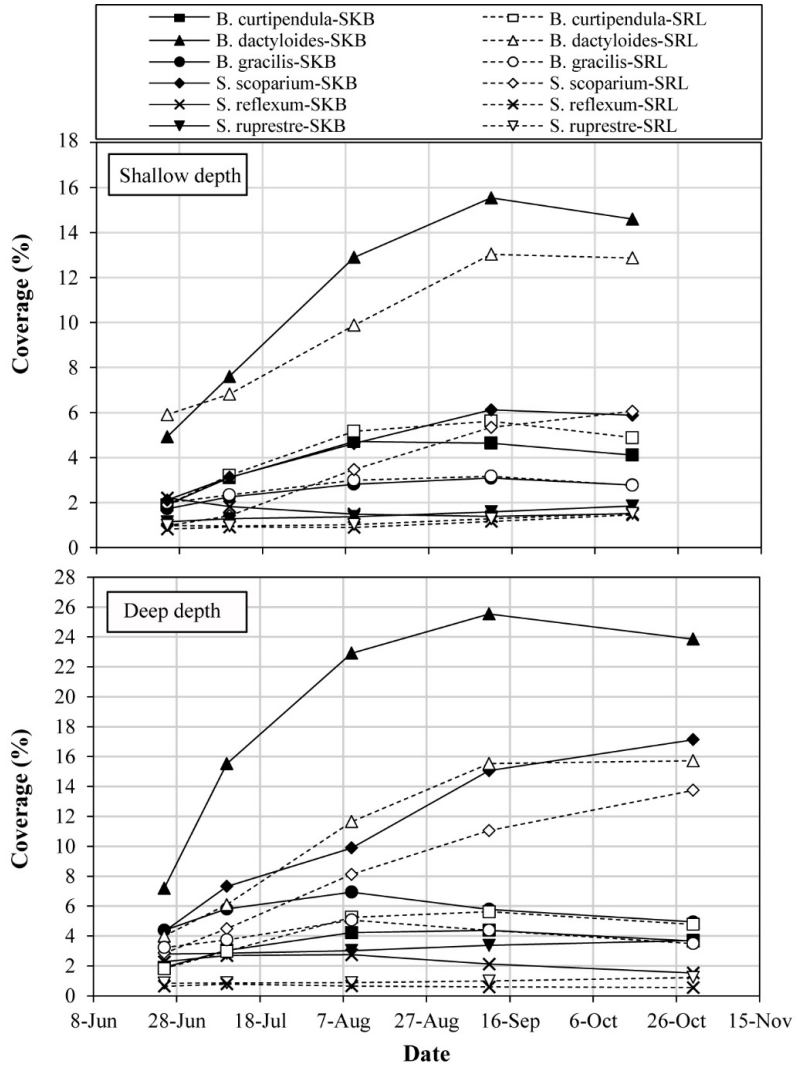
Our *STOTEN* paper focused on Mix B plants in the 8-inch and 4-inch beds

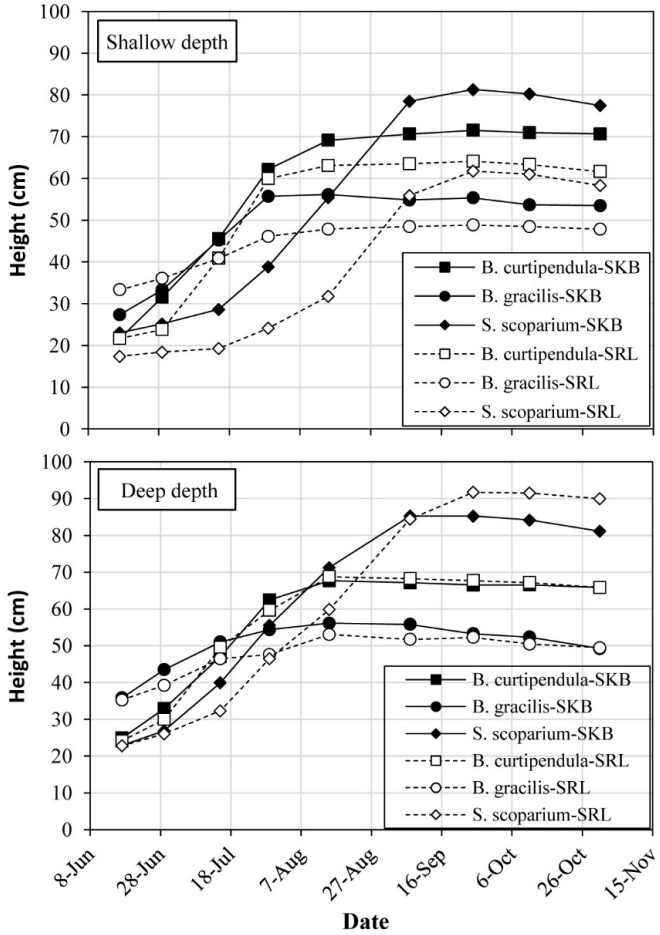
Height measurement (Photo: Lee R Skabelund)



Coverage measurement using Image J (Overhead photo: Allyssa Decker)







BuildEx (SKB) had a greater effect than Rooflite (SRL) on height for prairie grasses in the shallow profile, and a greater effect on coverage for prairie grasses and sedums in the deep profile. However, Rooflite had higher maximum water retention and almost always held more water than BuildEx. This suggests that, under the watering regimes employed, in combination with rainfall during the study period, the most limiting factor for plant growth was not substrate moisture.

Primary Research Question – Allyssa Decker (PhD candidate)

How do soil moisture, substrate type, and micrometeorological conditions affect **species survival** and **coverage of different green roof plant mixes** in different depths?

Hey! Is that Bruce Dvorak, thinking about his green roof book?

Vegetative Coverage Methods – Allyssa Decker

Photos by Lee R. Skabelund – mid-June 2018, and late-June 2020

Allyssa is currently finishing up work on her dissertation while teaching environmental science at Dickenson University as an assistant professor.

Allyssa took overhead photos every two weeks (starting in mid-June 2018 & during the 2019 growing season).

She measured plant coverage in each plot using ImageJ (Butler 2009).

And analyzed coverage values in SAS.

We monitored soil moisture & temperature *and* microclimatic variables on the APD-EGR while also documenting vegetation coverage in each plot, irrigating as needed, and keeping weeds out as best we could over two growing seasons (2018-2019).

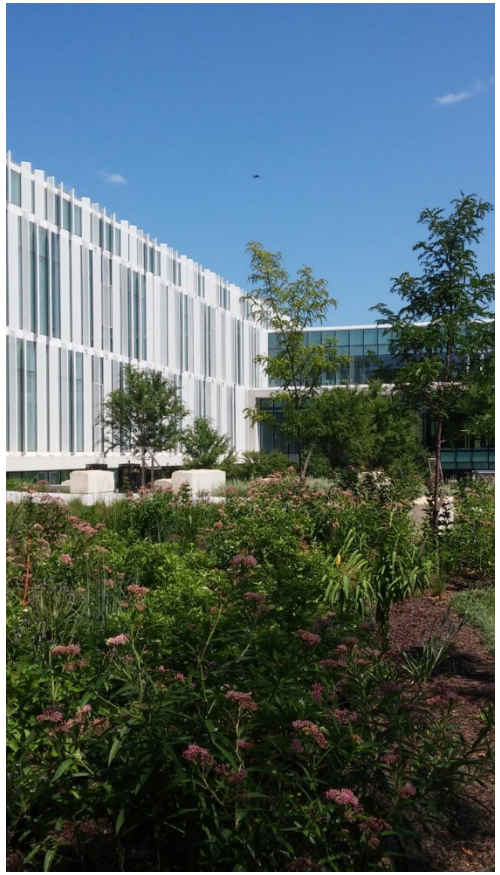
MIX A – all *Sedum* (6 species)

Mix B – 2 *Sedum* & 4 native grasses (including buffalograss)

Mix C – all natives (including 2 cool season & 2 warm season grasses and 2 forbs)

Overhead photos: Allyssa Decker

Thanks to Harman we took UAS imagery above the EGR twice in 2018: July 12th & Oct 27th.

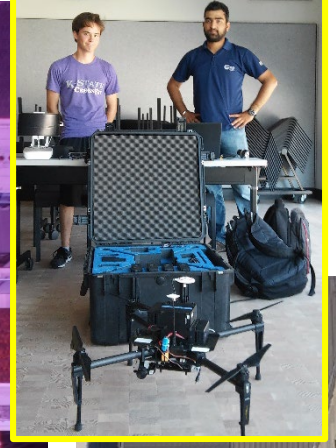


UAS flights by Harman Singh in mid-July and late October 2018 provided infrared, true color, and thermal imagery for the APDesign green roofs during their first full growing season.

UAS-collected data can be used to compare with ground-truthed data related to surface temperatures, soil moisture levels, plant growth, and stomatal resistance for selected vegetation—measurements taken to help us better understand plant stress and plant health.

2018

APD-EGR 12 July 2018 –
infrared UAS imagery - H. Singh

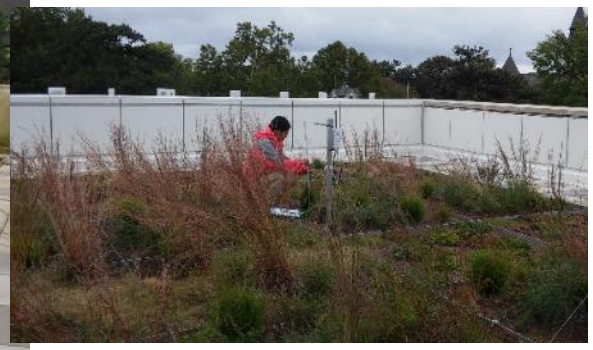


APD-EGR 12 July 2018 – color imagery - H. Singh

Aerial images will be a help as we assess changes in vegetative coverage over time.
UAS images may be good enough that labor-intensive ground measurements are not needed.

Jul 12, 2018

To determine how often to provide supplemental water (from cistern or spigot) **we examined our soil moisture readings, looked at the literature, and consulted Dr. Kirkham** (plant-soil-water guru) **& Danny Rogers** (irrigation expert in Bio-Ag Engineering).



Oct 12, 2018

Oct 15, 2018

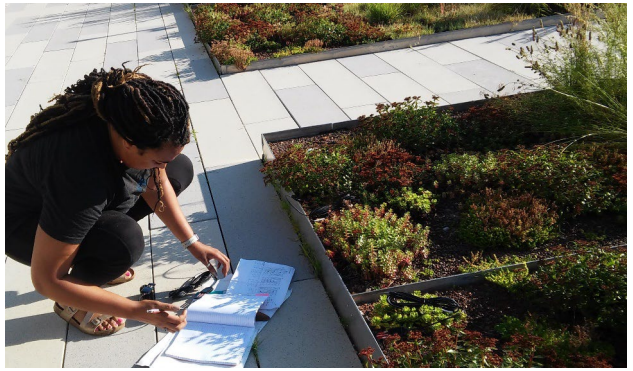
To better understand the nature of each substrate we looked at materials testing reports done prior to implementation, but also had samples tested for their physical & chemical properties (including particle sizes) **by a professional lab, and had substrate samples tested by the K-State Soils Testing Lab** (for nutrients, electrical conductivity, cation exchange & pH).

Agronomy and BioAg-Engineering faculty loaned a porometer and a soil moisture probe (HydroSense II) so we could take readings of plant respiration and volumetric water content in plots where porometer readings were taken.

2018

Jul 15, 2019 – adding sensor posts

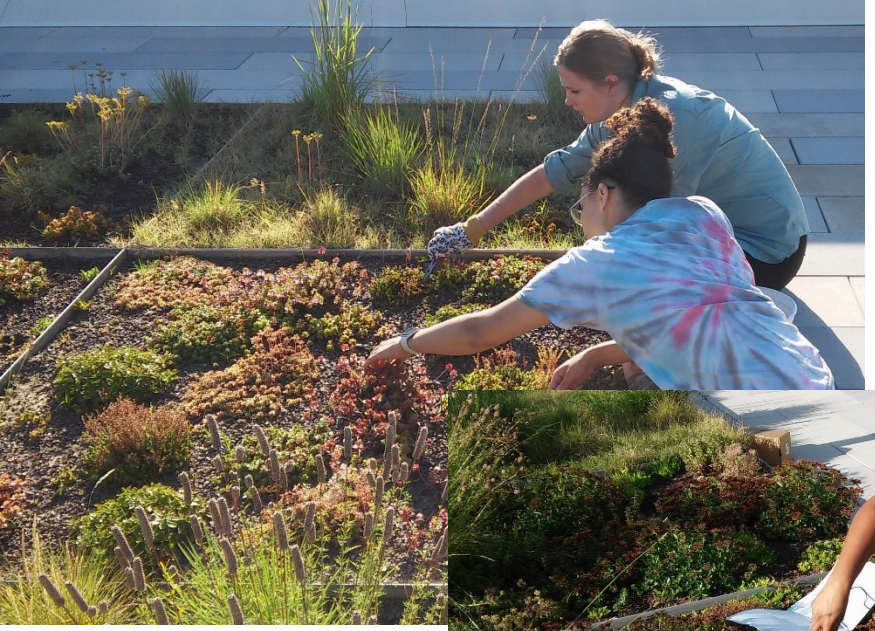
Jul 23, 2019 – adding temp & VWC sensors to sedum plots/cells



Jul 18, 2019 – 4-inch (L), 6-inch & 8-inch (R) beds

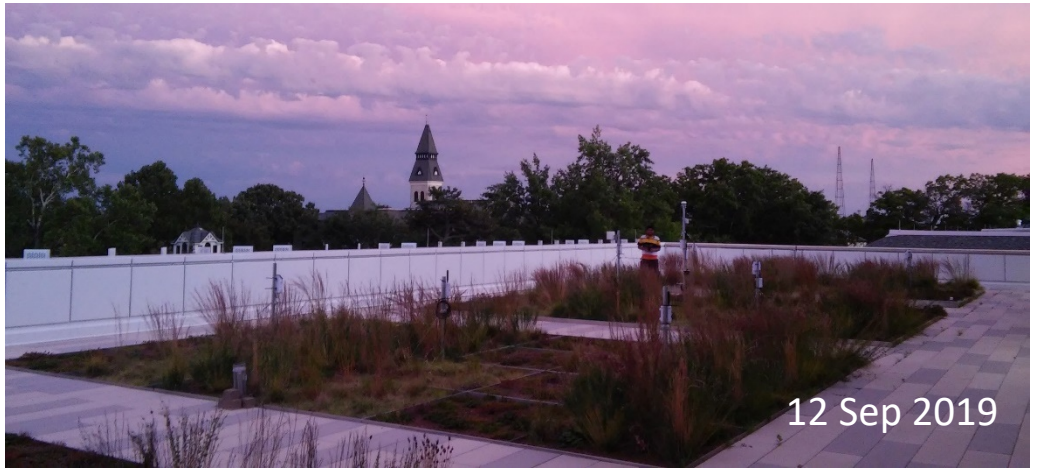
Capturing vegetation changes and various activities throughout the year (using full-size cameras & cell phone images) **is important as we observe, remember, ground-truth data & share results.** We've given many, many formal & informal green roof tours!

2019



APD-EGR weeding with two LA undergraduate volunteers
July 2019

5TM sensor burial w/Allyssa Decker



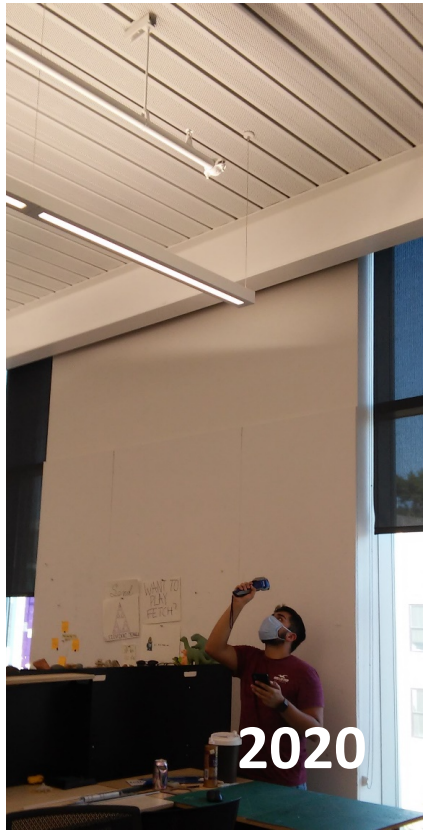
We involved volunteers and provided monetary compensation for some students **to help us weed.**

We added new sensors & data-loggers as donations, research grants, and other funds allowed.


APD-EGR weeding with Lekhon Alam, Allyssa Decker &
LAR 353 students (during a hands-on learning activity)
What is a weed?
18 Sep 2019

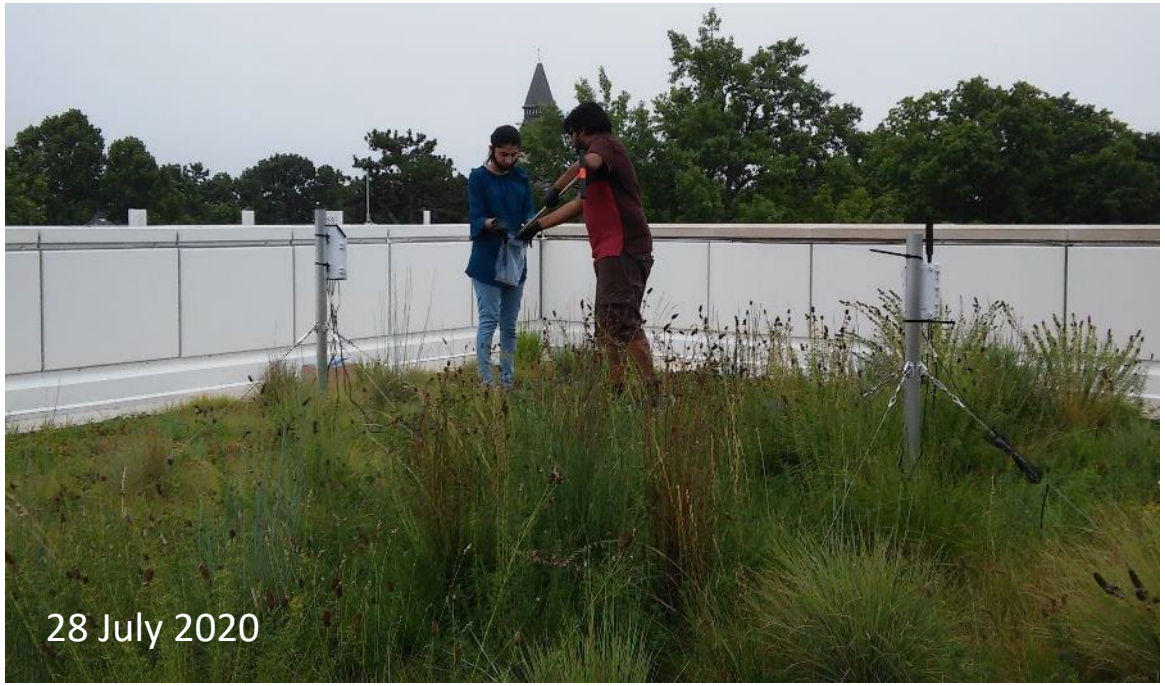
2019

A Thermal Camera is being used to document EGR & paving surface temps <u>and</u> temps in the studio below…



During the summer of 2020, I began working with Miguel Perez, a freshman interested in architecture & green bldgs.

He and Lekhon Alam are now collaborating with Michael Gibson, KSU-Architecture faculty member, **to determine the influence of the EGR on interior temps & HVAC needs.**



APDesign Experimental Green Roofs

Collage of three beds (4-inch, 6-inch, 8-inch, left-to-right)
(Photographs by M M Lekhon Alam, taken in May 2020)

Lekhon has received superb assistance for his soil (substrate) **microbiology & nematode sampling, lab work & data analysis from Dr. Charles Rice** (respected soil scientist), **Tim Todd** (plant pathologist & statistician) **& James Lin** (agronomy student). **His wife**, Tasmeen Akhter Tonima (an engineer), **also assisted with his research during this Covid-19 era.**

6 Nov 2020

Lekhon Alam's Root Biomass Sampling
with LRS & James Lin (Agronomy)

2020

Primary Takeaways from Allyssa Decker's Research (to be discussed with her PhD Committee):

1. **Substrates vary in how much water they can hold & the energy status of water in a substrate.**
It is harder for plants to pull water from rooflite (very important at low levels of substrate moisture).
2. **There is not much difference in how the two different substrates dry out of after a rain event.**
(Allyssa: "I analyzed 1hr and 24hr data – much of the water is lost in this period – in the future I recommend looking at soil moisture recession after the initial pulse of water leaves the substrate." This type of ongoing analysis should help us determine if there are meaningful differences in how the two substrates dry out.)

3. **At the shallower depths we see more of a difference in plant cover and biomass (less of both).**
4. Not much difference in above ground biomass between the substrate types – only for a few species.
5. **Native species mixes and hardy sedum mixes are excellent contenders for GR plantings.**
(It will be important to see what happens to the sedum species in Mix B.
I sense they will not do well in the plots with extensive buffalo grass spread.)

6. Plant coverage is still above 65% in 8-inch bed for the mixes at end of 2019 – Mix A averaging 65% and Mixes B&C averaging 85%; greater cover in the sandy BuildEx than in the Rooflite in the 8-inch plots.
7. By the end of 2019 6-inch bed plant cover ranges from 40 to 85% – lowest is in Mix A, then C, then B.
8. 4-inch – No differences between the substrates by 2019, however, plant cover ranges from 30% to 55-60%, with A being the lowest and Mix B and C having greatest percent cover.
9. **Green roofs are almost a perfect habitat for buffalo grass.** It thrives in rocky and sandy soils and on the green roof there is not much competition with taller grasses for sunlight. [Buffalo grass is not visually prominent, which may be a concern depending on the goals of the roof.]

Manhattan (Seaton/Regnier Hall & Memorial Stadium) green roof findings & observations:

- **Aesthetic values are influenced by knowledge *and* how one views the natural world, the built environment, and how we relate to each.**
- **Substrate types matter; lighter East Memorial Stadium Green Roof (EMS-GR) soils dry out more quickly and have a wider range of moisture levels.**
- **Roof slopes matter; steep sloped green roofs need more supplemental irrigation (typ. more than once a week during the hottest & driest parts of the growing season—which can occur anytime between early April and late October).**
- **Some irrigation is needed during dry periods to retain vegetative coverage and healthy plants.**
- **Vegetative cover matters in tempering heat loads & retaining moisture; plant survival/health is dynamic… Irrigation is needed to insure near-to-full surface coverage by living plants, but is not needed every day. Too much irrigation is not helpful (from a water conservation perspective & for some native plants). A number of native plants can survive without irrigation on green roofs in our climate; however, supplemental water & management are important to remove pesky weeds and help cool the roof with plant biomass and shade.**
- **EMS-GR plants look lush (due to ample irrigation), but contain lots of agricultural weeds.**
- **West MS-GR plants look less abundant (than the EMS-GR), but contains a strong matrix of native grasses (many were in the specified seed mix, but grasses were left out of the EMS-GR seed mix).**
- **Many pollinators and birds (including an occasional meadowlark and often seen red-tailed hawk) frequent the Memorial Stadium & Seaton Hall green roofs. Cotton rats and ground-nesting bees burrow into the sand & expanded shale substrate on the EMS-GR.**
- **Lack of contractor experience in the region influences implementation & establishment practices.**
- **Specifications are not always followed and implementation requires active oversight and dialogue. Lack of weed seed removal influences species composition and vegetative coverage. There are many volunteer plants to consider (and potentially clip or remove) in urban & former agricultural settings.**
- **Involving maintenance staff & other stakeholders in the design discussions (early on & after final design) is very important. This engagement is needed for green roofs, rain-gardens, bio-retention areas, and all other types of landscape design work.**

Kansas State University APDesign Experimental Green Roof

Methods for examining plant growth, substrate moisture content, and other variables on an experimental green roof in the Great Plains, USA

Associate Professor Lee R. Skabelund, ASLA, BLA, MLA, RLA
Landscape Architecture and Regional & Community Planning, Kansas State University

with Allyssa Decker (KSU-Environmental Design & Planning PhD candidate), Priyasha Shrestha (KSU-MLA 2019), Dr. Jialin Liu (2018-2019 KSU-Visiting Scholar from Southwest Univ., China), Lekhon Alam (KSU-EDP PhD candidate), Yuting Gao (KSU-EDP PhD student), Miguel Perez (KSU-Architecture student), Timothy Todd (KSU-Plant Pathology faculty), Dr. Mary Beth Kirkham (KSU-Agronomy, Distinguished Professor of Plant-Soil-Water relations), Dr. Trisha L. Moore (KSU-Biological & Agricultural Engineering, Assistant Professor), Mary Knapp (KSU-Climatologist), Dr. Charles W. Rice (KSU-Agronomy, Distinguished Professor of Soils & Carbon Sequestration), Michael Gibson (KSU-Architecture), Dr. Gerard Kluitenberg (KSU-Agronomy, Professor of Soil Science), Dr. Ajay Sharda (KSU-BAE, Associate Professor), Harman S Sangha (KSU-BAE Masters of Science 2020), and James Lin (KSU-Agronomy student)

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http://www.k-state.edu/greenroofs/