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Credit Valley Conservation – inspired by nature

Emerging Technologies of Blue-Green Infrastructure and Low Impact Development for Stormwater Management

Tamer Almaaitah
Darko Joksimovic

Toronto Metropolitan University
Civil Engineering

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OUTLINE

- **Introduction**
  - Problem statement – Motivation - Objectives
- **Methodology**
  - Systematic literature review - Field monitoring – Data collection and Analysis
- **Results**
  - Hydrologic and thermal performance
- **Conclusions**
- **Future research**

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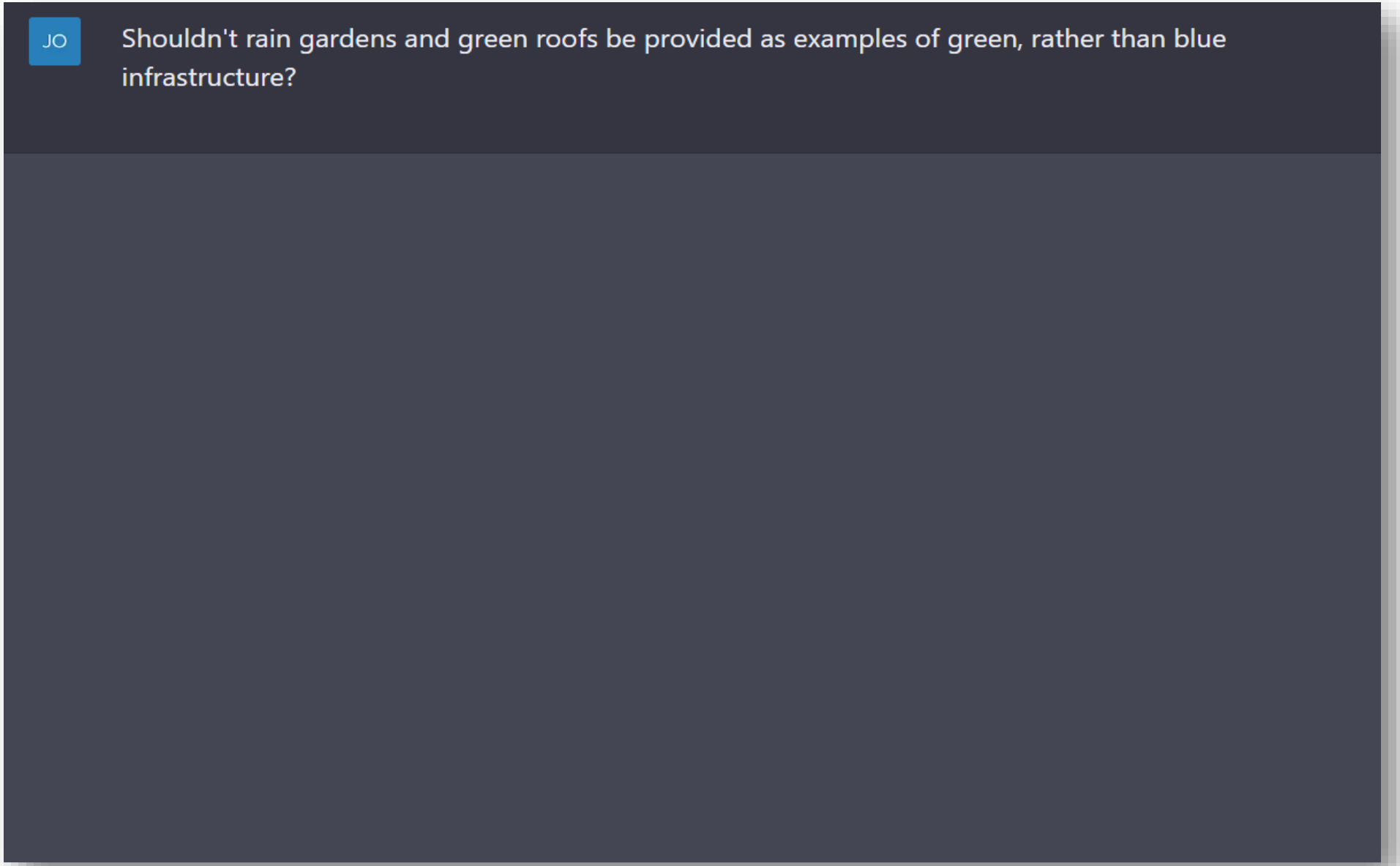
What is Blue-Green Infastructure?



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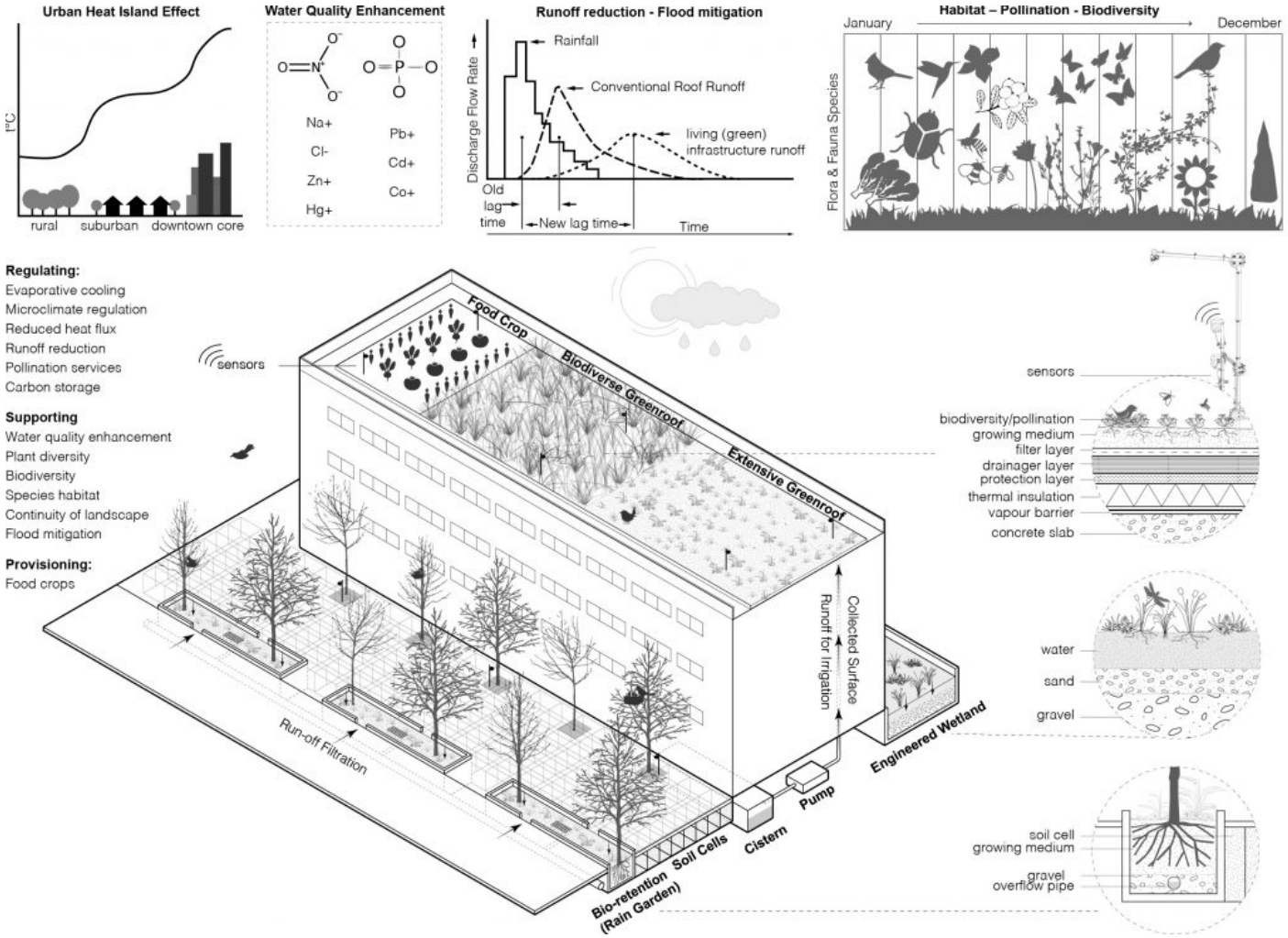
- DesignLIFES - Design of Living Infrastructure for Ecosystem Services

  … train the next generation of engineers, landscape architects and scientists in the interdisciplinary professional and technical skills they will need to design, create and manage living and green infrastructure for Canadian cities.

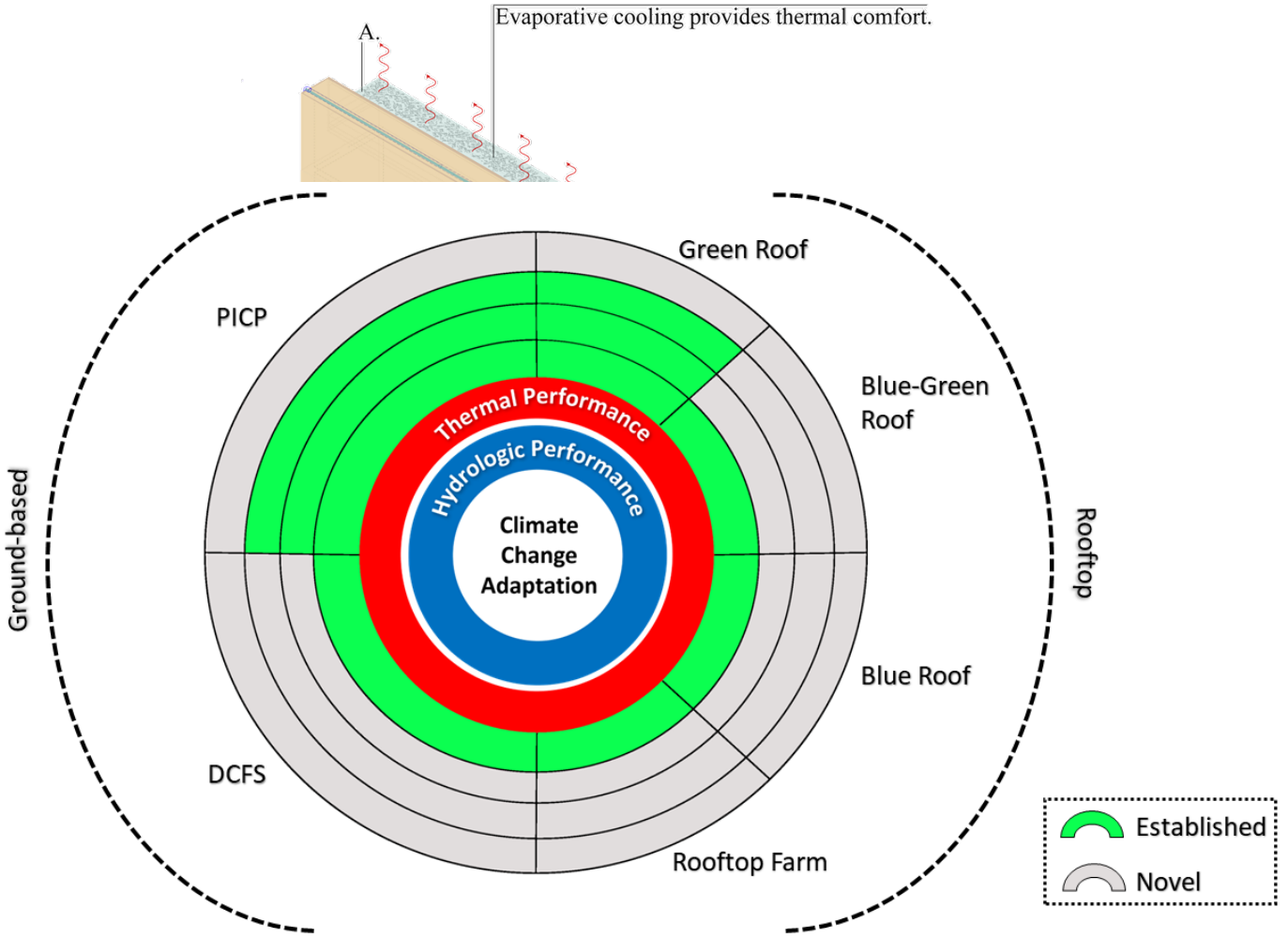


https://designlifes.civmin.utoronto.ca/

- Focus on
  - Rooftop and ground-based
  - New and emerging technologies
  - Climate change adaptation

    urban runoff and heat
  - Internet of Things (IoT)

    "data is the new oil"
- Local sites and facilities



Holistic Design: Grey, Green and Blue Infrastructure

A. Blue Roof
B. Tree Planting
C. Sewer Connections
D. Rain Barrel
E. Permeable Paving
F. Green Roof (Intensive; Semi Intensive; Extensive)
G. Rain Garden
H. Fountains
I. Underground Detention

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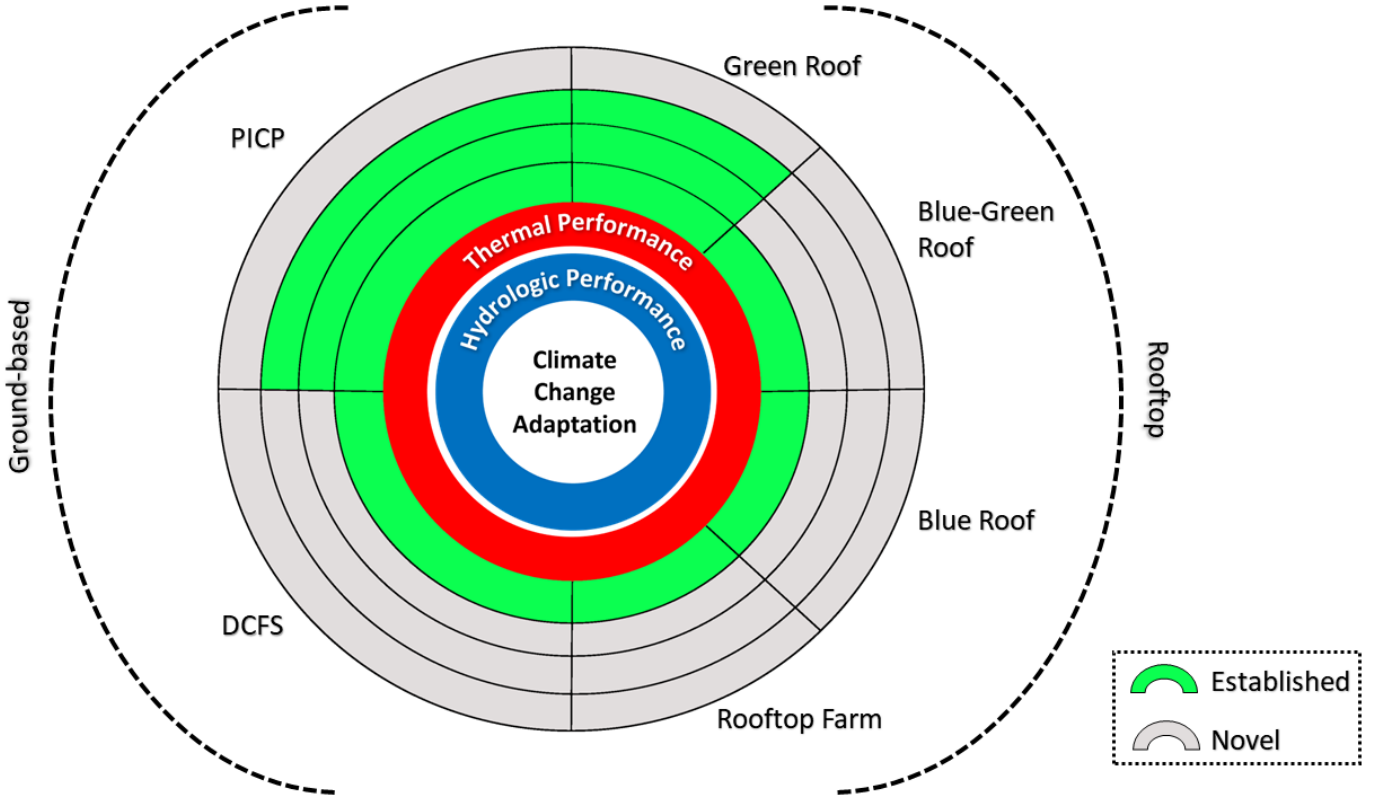
- Research objectives

1. Evaluate of the state-of-the-ar
2. Quantify and compare therma monitoring
3. Assess wireless monitoring ap



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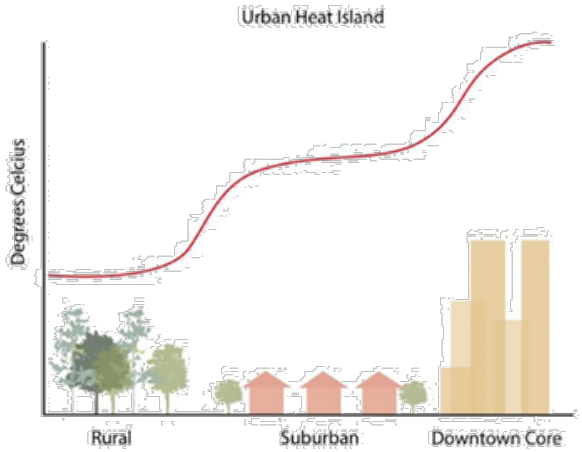
Blue and Blue-Green Infrastructure (BGI)

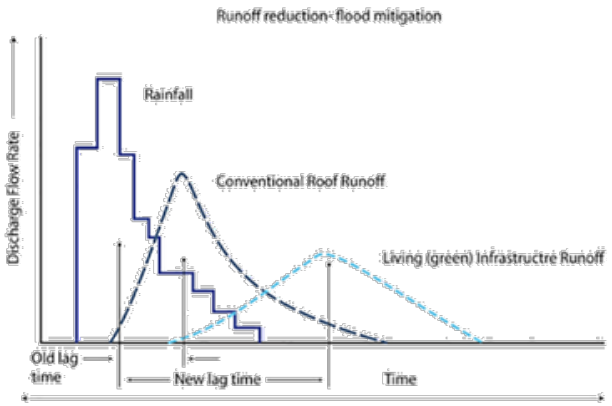
Records identified through database searching: Engineering Village and Scopus (n = 419)

Records after primary screening (n = 156)

Records after full-text assessment (n = 135)

Articles included (n = 32)





UHI Mitigation

BGI lower surface and air temperature

Cooling effect of BGI differs throughout the urban layers

Thermal performance is affected by the size and geometry of BGI

Barriers to BGI

Lack of multilevel coordination

Budget constraints and funding schemes

Absence of risk reduction frameworks

Existing maintenance practices

Stormwater Management

Using BI in combination with GI enhances hydrologic performance

Retrofitting neighborhoods with BGI reduces flood risks

Integrating BGI with grey infrastructure is a promising strategy

Research Gaps

Discrepancy between urban scales

Lack of multifunctionality studies on BGI

Distinction between natural and engineered BGI

Uncertainties of BGI performance in comparison to Green Infrastructure

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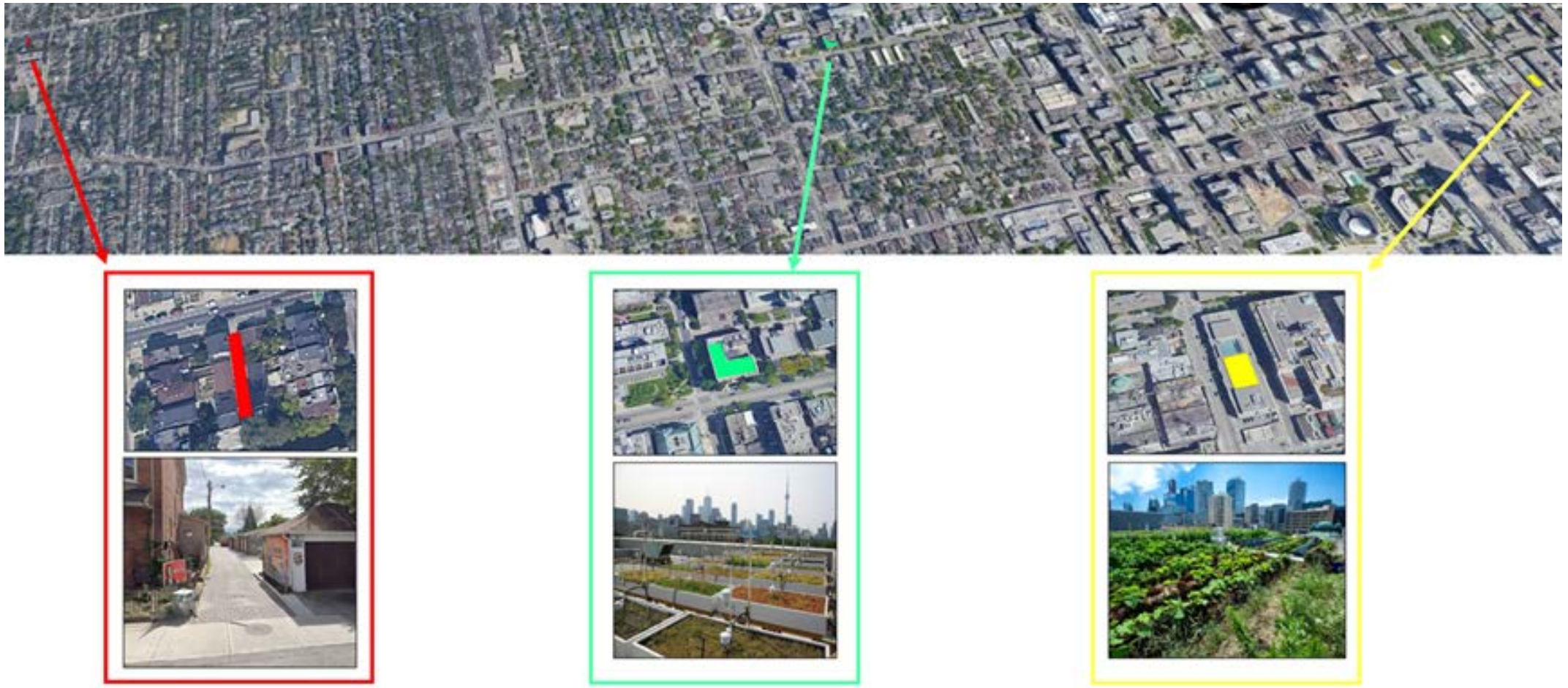
Field Monitoring in Downtown Toronto



Crawford Laneway

Road

UofT Gritlab

Rooftop Modular

TMU Urban Farm

Rooftop Full-Scale

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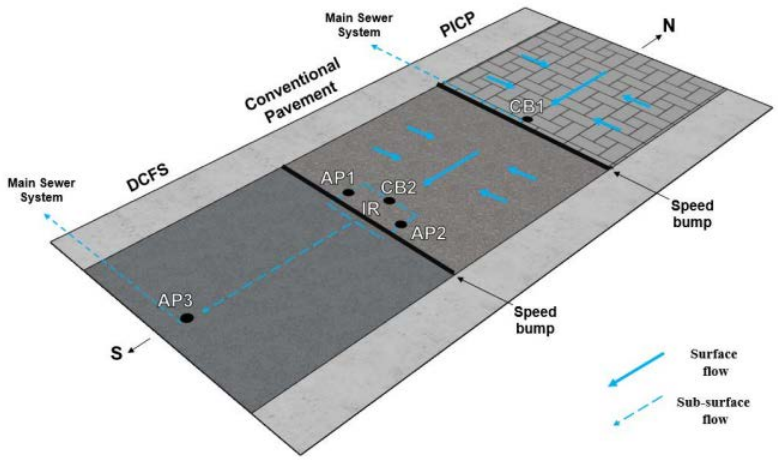
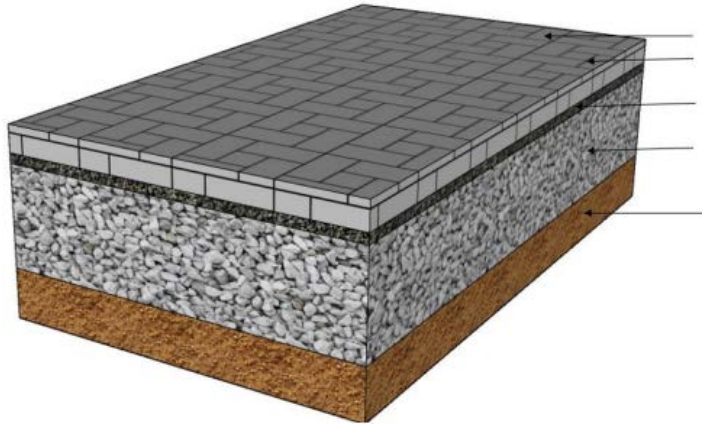
Field Monitoring: Full-Scale and Experimental Setups



Crawford Laneway

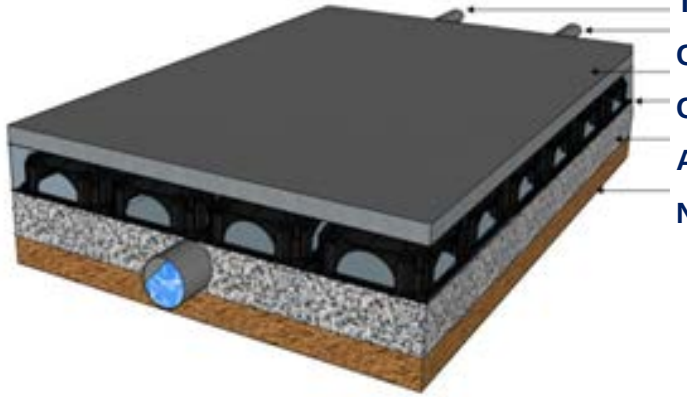
Road

PICP-DCFS



PICP

- Pavers
- Bedding Layer
- Aggregate basecourse
- Native soil



DCFS

- Transfer Pipes
- Concrete Pavement
- Cupolex® Domes
- Aggregate Basecourse
- Native Soil

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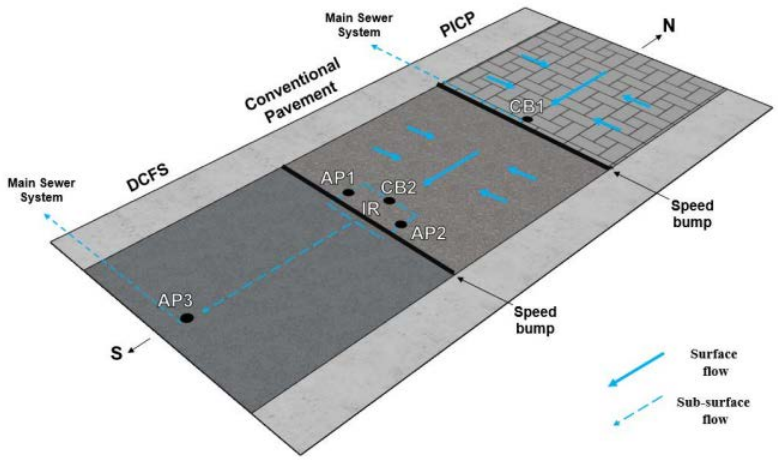
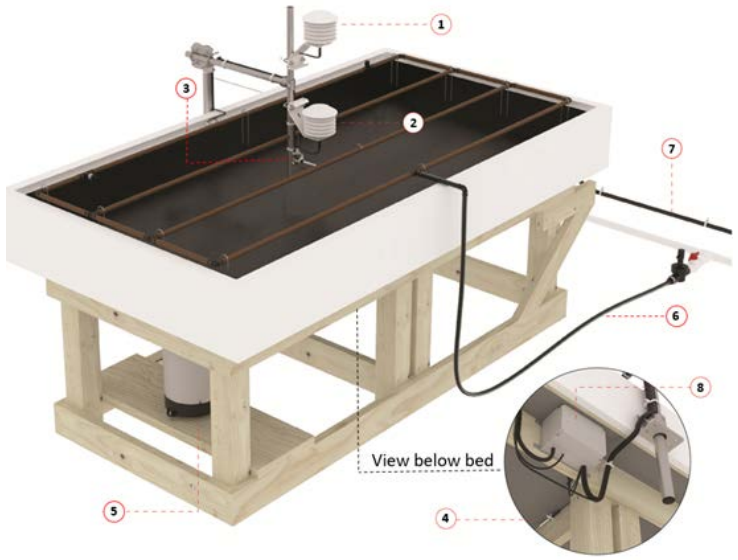
Field Monitoring: Full-Scale and Experimental Setups



Crawford Laneway

Road

PICP-DCFS



U of T's Gritlab

Rooftop Modular

Extensive GR and BGR

Check Dam BR

Green Roof

Vegetation

Growing Media

Drainage Layer

Blue-Green Roof

Vegetation

Growing Media

LARGER Drainage Layer

Blue Roof

Check Dams

Orifices

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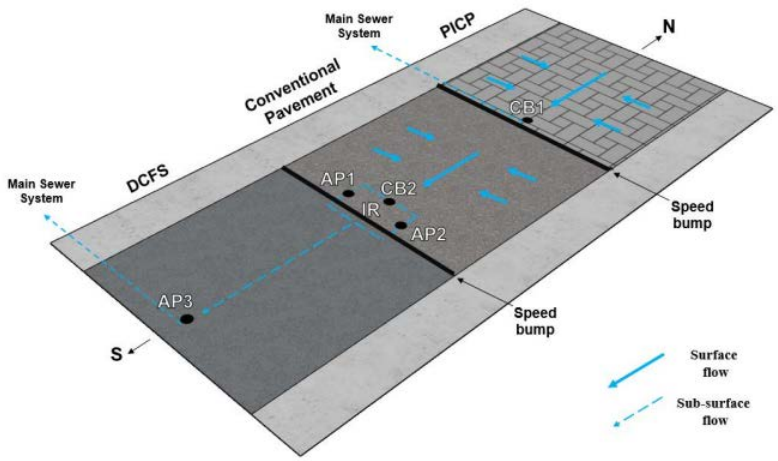
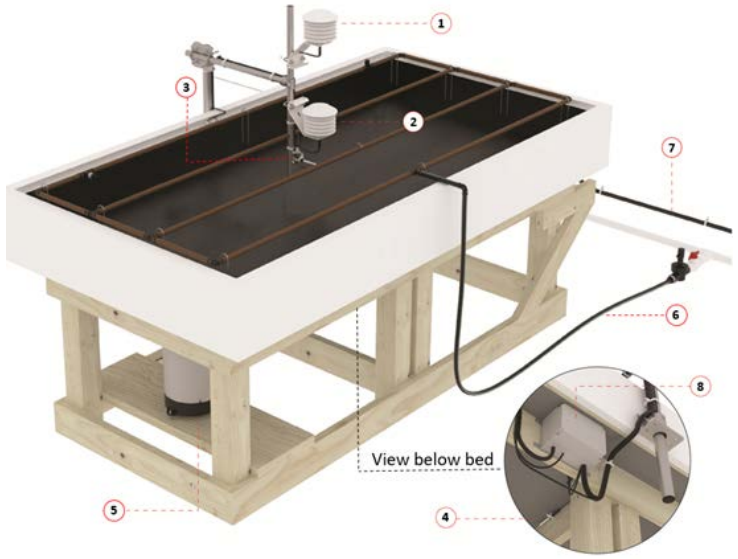
Field Monitoring: Full-Scale and Experimental Setups



Crawford Laneway

Road

PICP-DCFS

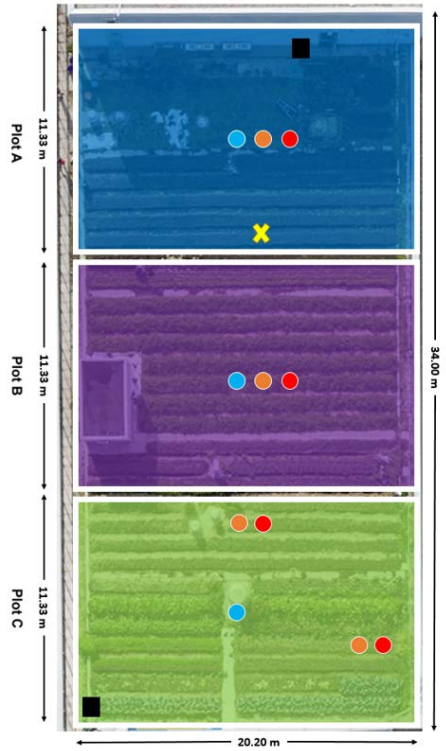


U of T's Gritlab

Rooftop Modular

Extensive GR and BGR

Check Dam BR



TMU's Urban Farm

Rooftop Full-Scale

Intensive BGR

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Field Monitoring and Laboratory Testing



















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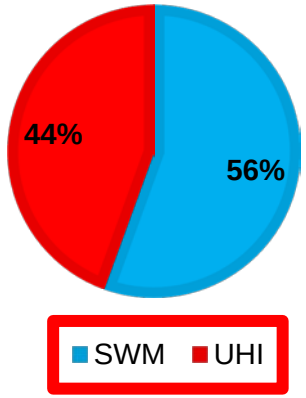
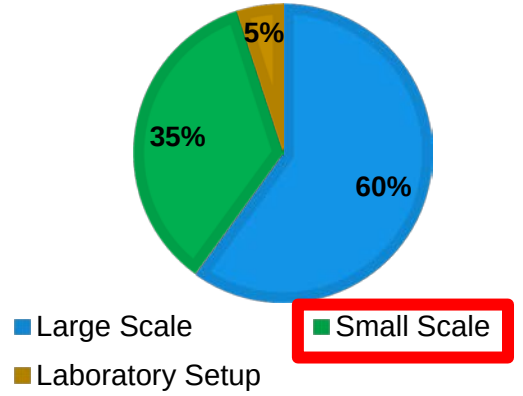
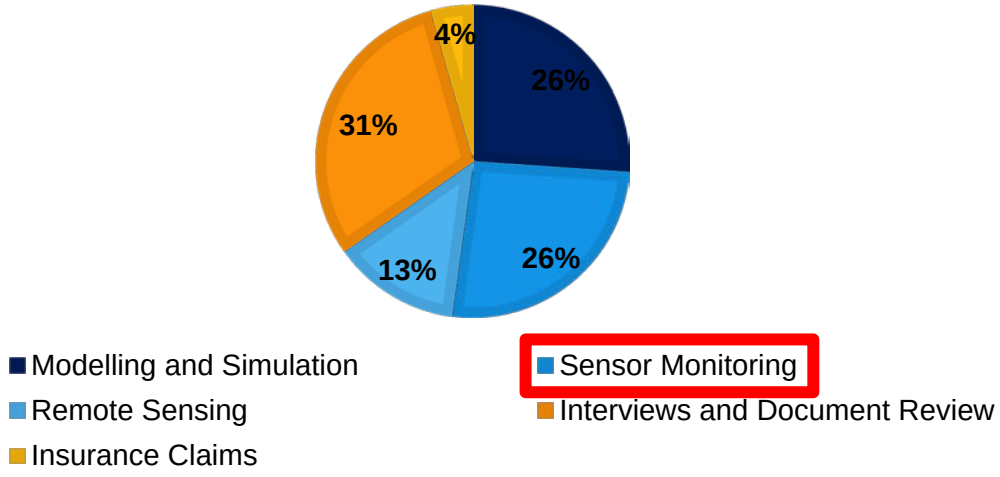
Results of the Systematic Literature Review

- Evidence of urban runoff and heat mitigation by BGI was found
- Most studies focused on one benefit at a time (e.g., hydrologic or thermal)
- Two-thirds of the selected studies were performed on a large urban scale
- A variety of research approaches were followed







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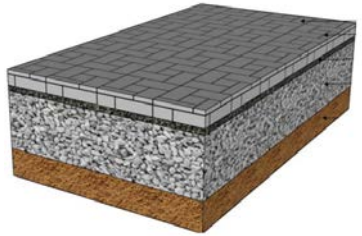
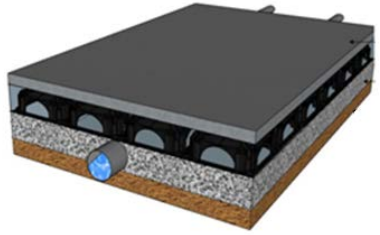
Permeable Pavers and Dome Concrete Forming System

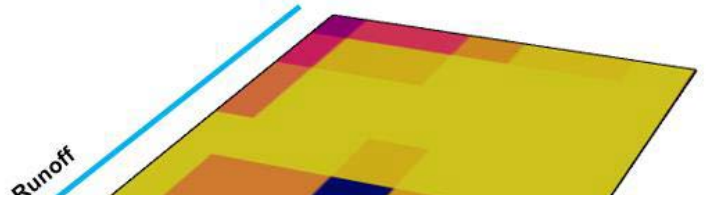
Hydrologic Performance

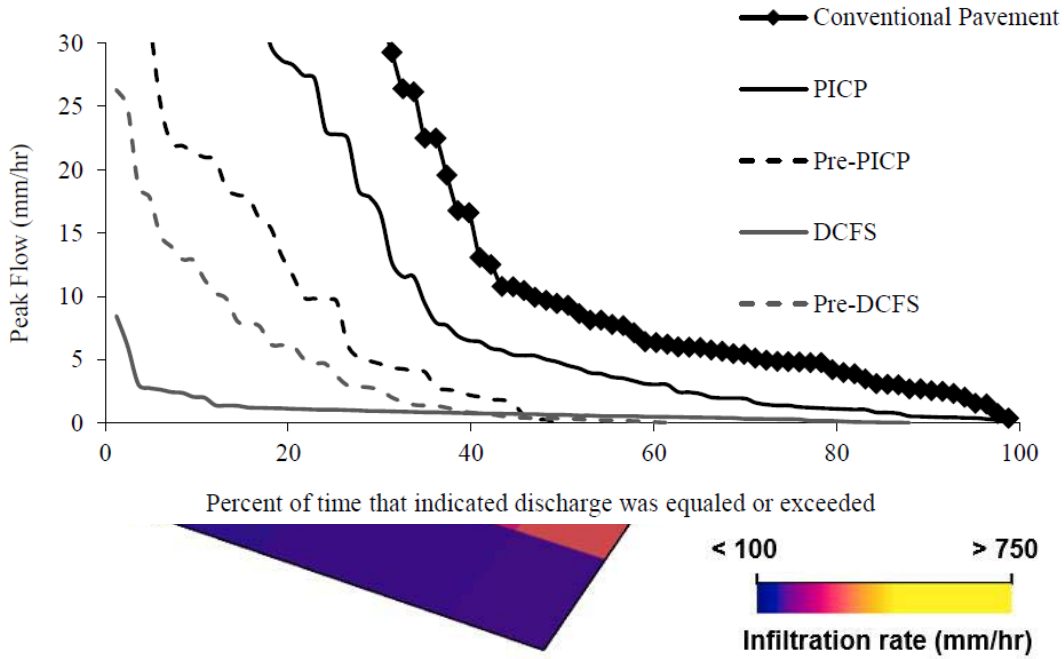




Compared to a conventional concrete pavement

	PICP	DCFS
Runoff Volumetric Reduction	**33%**	**85%**
Runoff Peak Flow Reduction	**43%**	**89%**
Runoff Delay	**Moderate**	**High**





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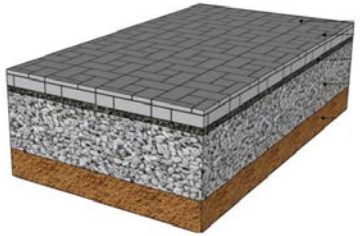
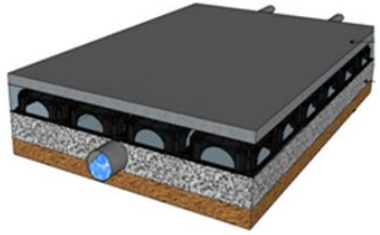
Permeable Pavers and Dome Concrete Forming System

Thermal Performance





	PICP	DCFS
Surface Temperature	No distinguishable difference	**Higher (2.3 °C)**
Near-Surface Air Temperature	No distinguishable difference	**Higher (0.8 °C)**

Compared to a conventional impervious concrete pavement

PICP

Conventional and DCFS

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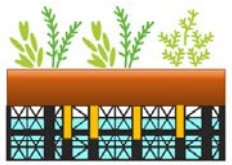
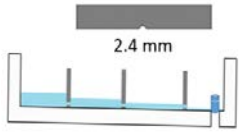
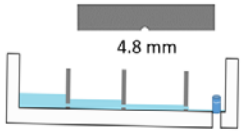
Extensive Green, Blue-Green and Blue

Hydrologic Performance

Six Experimental Modules





	Green FLL	Green Organic	Blue-Green FLL	Blue-Green Organic	Blue Smaller Orifices	Blue Larger Orifices
Retention	51%	47%	51%	63%	51%	32%
Peak Attenuation	Moderate	Moderate	High	High	Moderate	Moderate
Peak Delay	50 minutes	2 hours	2 hours	6 hours	15 minutes	12 minutes

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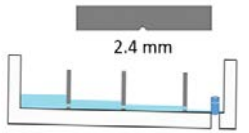
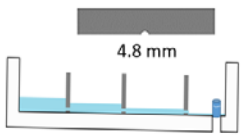
Extensive Green, Blue-Green and Blue

Thermal Performance

Six Experimental Modules

	 Green FLL	 Green Organic	 Blue-Green FLL	 Blue-Green Organic	 Blue Smaller Orifices	 Blue Larger Orifices
Near-Surface Air Cooling	1.6 °C	2.9 °C	2.8 °C	2.9 °C	2.2 °C	2.2 °C
Diurnal Air Cooling	Maximum cooling in the afternoon				Maximum cooling in the evening	
In-substrate Temperature	Higher	Higher	Lower	Lower	-	-

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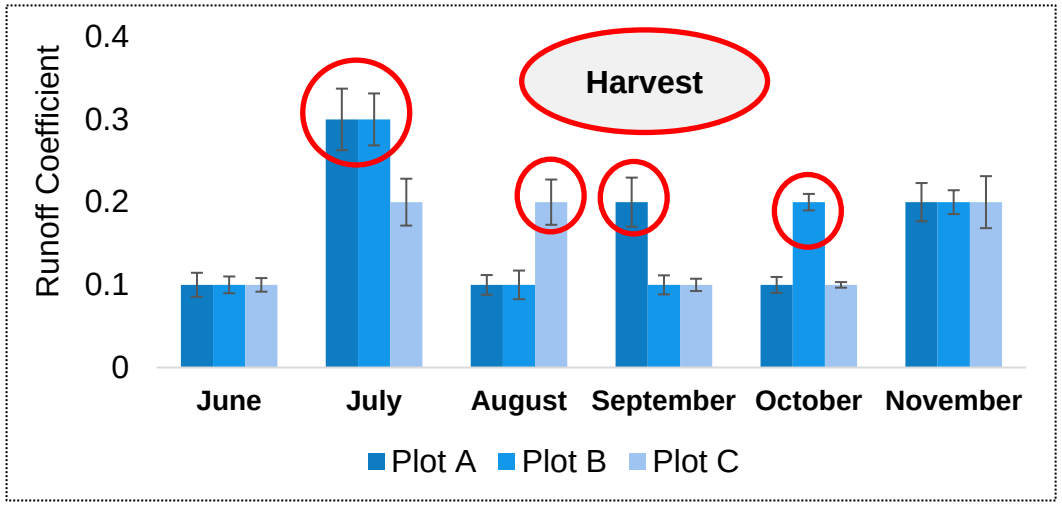
Farmed Intensive Blue-Green Roof

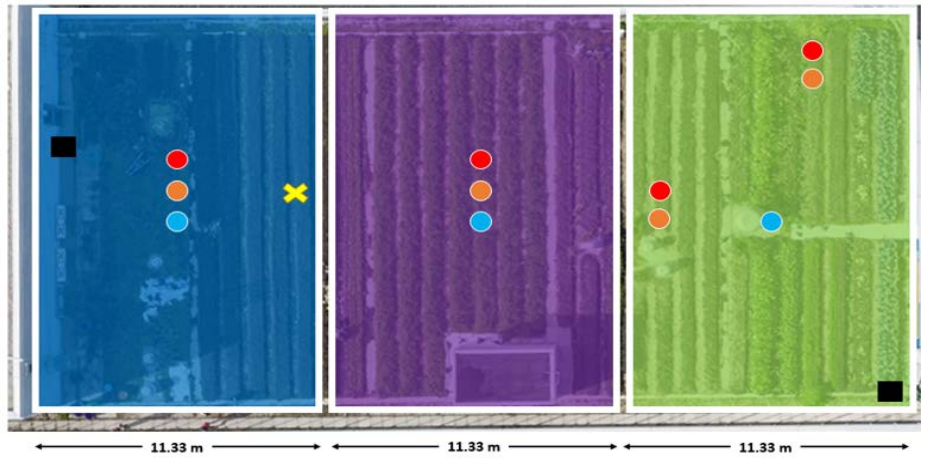
Hydrologic Performance

Three Full-Scale Plots

Key Observation

Planting and harvesting activities impacted the hydrologic performance





Plot	(A)	(B)	(C)
Retention	87%	85%	88%
Peak Attenuation	84%	82%	85%
Peak Delay	8 hours	8.1 hours	7.7 hours

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Farmed Intensive Blue-Green Roof

Thermal Performance

Seven Species







	Quick Weed	Milkweed	Potato	Squash	Beet	Tobacco	Okra
Near-Surface Air Cooling	0.5 °C	1.4 °C	1.4 °C	1.4 °C	2.5 °C	2.5 °C	2.5 °C
Diurnal Air Cooling	Maximum Cooling in the afternoon & Warming effect in the early morning						

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IoT - wireless sensor monitoring of BGI

LPWAN Sensors

Gateway

Network Server

THE THINGS NETWORK

Application Server

ubidots

AWS IoT

DATA AGGREGATION AND ANALYTICS

ThingSpeak

Wi-Fi/ Ethernet/ Cellular

LoRaWAN

Source: Semtech

End-to-End Secured Payload

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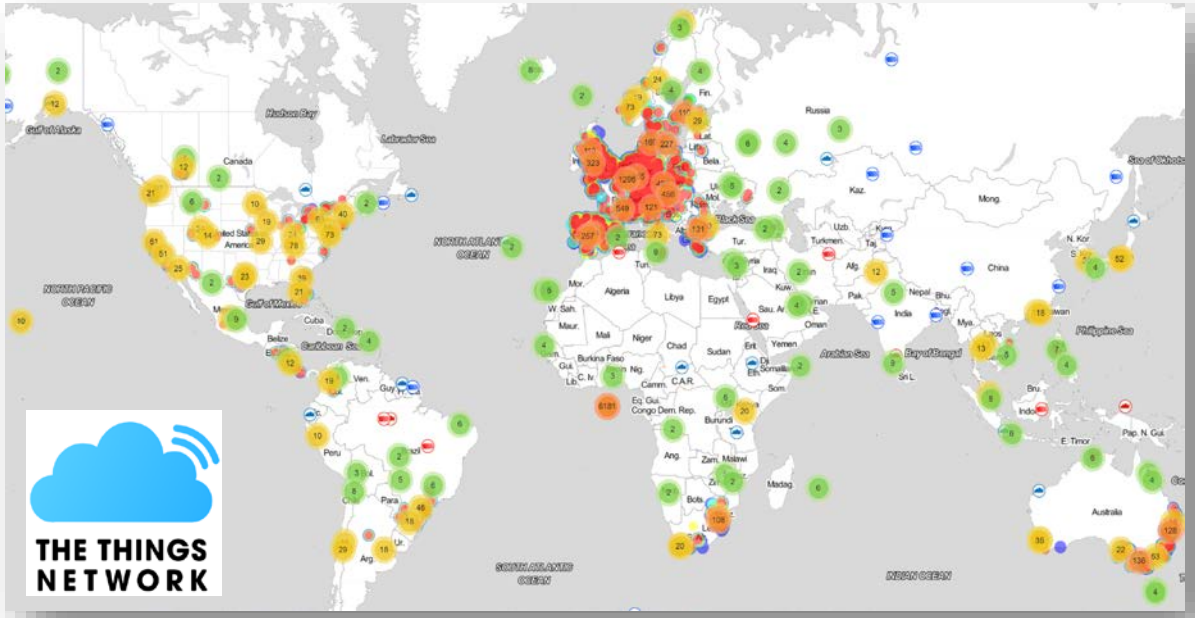
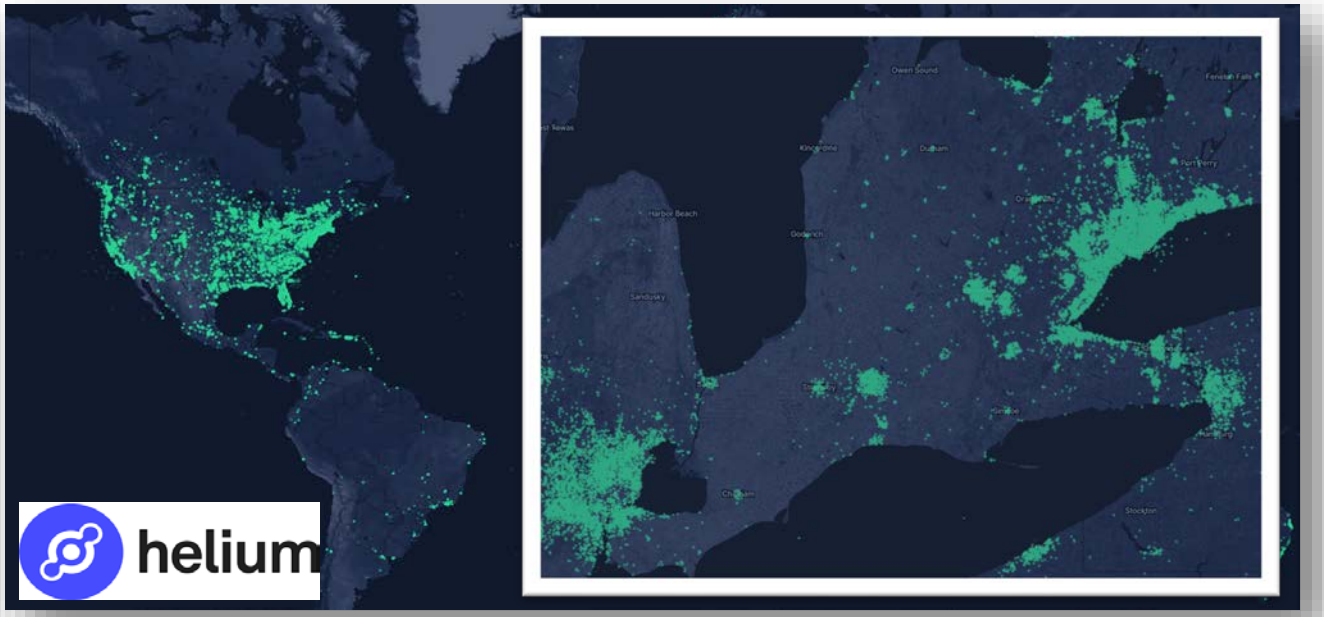
IoT - wireless sensor monitoring of BGI





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Conclusions

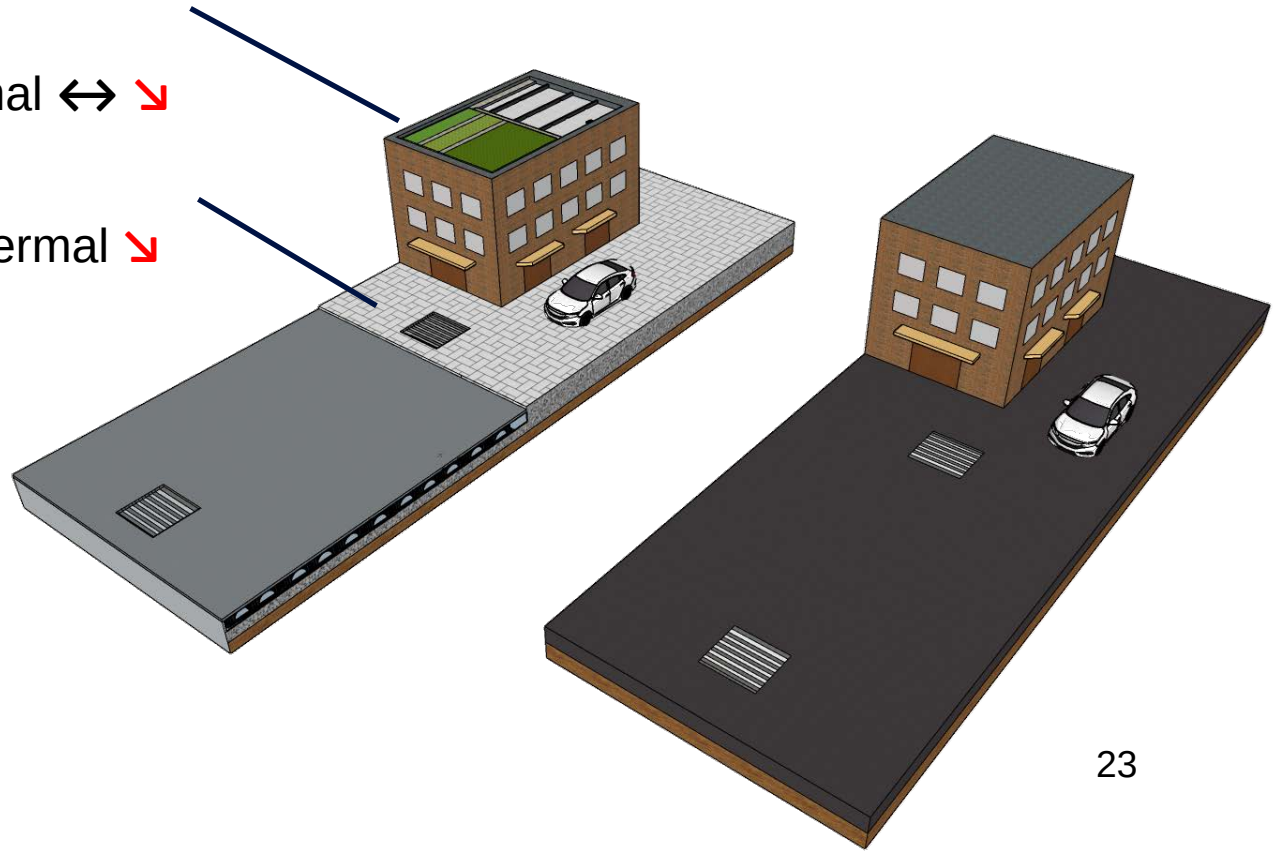
- Defining Blue-Green Infastructure using ChatGPT takes time

Relative to extensive Green Roofs:
- Blue: hydrologic ↔ ↘, thermal ↔
- Blue-Green: hydrologic ↔ ↗, thermal ↔ ↗
- Intensive, farmed Green: hydrologic ↔ ↗, thermal ↔ ↘

Relative to PICP
- Dome concrete forming systems: hydrologic ↗, thermal ↘

- IoT developments are enabling ‘smart’ BGI

↘ inferior
↔ comparable
↗ superior



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Future Research

- Rooftop farming (+ other BGI)
  - Plant growth and health
  - Terrestrial + remote sensing (performance, O&M)
- Development and testing of other sensors (e.g. water level and flow, machine vision)
- Long-term performance assessment
- Modelling – coupled hydrologic and thermal

Acknowledgments

- TMU's Urban Farm Team

- DesignLIFES and Gritlab Team

- Industrial Partners
  - ABT, Inc.
  - Bioroof Systems Inc.
  - Dufferin Construction
  - Pontarolo Engineering Inc.

- NSERC CREATE through the DesignLIFES program
- Transportation Services Division at the City of Toronto

List of Publications

- The potential of Blue-Green infrastructure as a climate change adaptation strategy: a systematic literature review
- Impact of design variables on hydrologic and thermal performance of green, blue-green and blue roofs
- Hydrologic and thermal performance of a full-scale farmed blue–green roof
- Hydrologic performance of permeable pavers and a dome concrete forming system: a comparative study
- Real-time IoT-enabled water management for rooftop urban agriculture using commercial off-the-shelf products

Blue-Green Systems IWA PUBLISHING

Blue-Green Systems IWA PUBLISHING

water MDPI

Journal of Hydrologic Engineering ASCE American Society of Civil Engineers

chemistry proceedings MDPI

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