EXPERIENCE WITH COLLABORATIVE RESEARCH ON THERMAL CHARACTERISTICS OF LOW IMPACT DEVELOPMENT STRATEGIES

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1 ABSTRACT

As the urbanization increases, stormwater runoff heated by urban surfaces during summer directly flows into lakes, streams, and bays, where it mixes and potentially increases the base temperature of receiving waters. Low impact development (LID) control measures are well known to tackle urban stormwater runoff, but little is known about the potential of these LID control measures in reducing the stormwater runoff temperature. To examine this potential, a controlled test is designed and conducted in the Green Infrastructure Laboratory (GIL) at Auburn University. The goal of the research is to assess how LID stormwater control measures affect stormwater runoff temperature. Particularly, pervious and impervious concrete, sod, brick pavers, and rain gardens are involved in the test. Since there are the very limited reference for this kind of research, the focus on process and result of the test weighs equal in achieving better research outcomes. Thus, instead of showing the core testing results, this paper aims to discuss the test setup, research methods and process. More importantly, professor and students from the Department of Landscape Architecture at Auburn University have involved in this laboratory-scale research. By discussing how we contribute to the research from the aspects of test-oriented work and test outreach, we start to examine the ability of landscape architecture to actively engage experiment-based research. This also pushes the boundaries of landscape architecture to a much more detailed material thinking, and helps to understand complex landscape performance of LID practices through the thermal aspect.

1.1 Keywords

Collaboration, Thermal Impact, Low Impact Development, Maintenance, Outreach

2 INTRODUCTION

As urbanization increases, massive development changes natural landscape (forest, prairie, grassland, wetland, etc.), and alters the urban ecosystem and micro climate. The process of urbanization also posts pressures on the hydrologic cycle (Shuster, Bonta, Thurston, Warnemuende, & Smith, 2005). Particularly, developed urban surfaces such as residences, buildings, parking lots, roads, and other types of artificial surfaces dramatically reduce the area that stormwater runoff flows through. This results in the decline of stormwater infiltration and the increase of the risk of flooding. Low impact development (LID) is known as a land development strategy for managing stormwater at the source with decentralized micro-scale control measures (Ahiablame, Engel, & Chaubey, 2012). These control measures innovatively increase stormwater infiltration, and relieve the conventional infrastructure's pressure during extreme storm events under potential climate change. Many studies have focused on the capacity of LID control measures in the aspects of volume absorption, effectiveness of vegetation, and pollution reduction. However, the thermal characteristics of these LID control measures have not been fully understood (Green Infra Lab, 2017). The thermal regime of the environment is altered when urbanization constructions happen. Urban imperviousness increases surface temperatures in hot summer days (Morabito et al., 2017). Research has shown that the thermal properties of paving material can reach temperatures in excess of 60 °C, with much of the heat concentrated near the surface (Asaeda, Ca, & Wake, 1996). The pervious pavement has been studied for mitigating urban heat island effect (Kaloush, Carlson, Golden, & Phelan, 2008), as well as the impact on the stormwater management (Li, Harvey, Holland, & Kayhanian, 2013). There are few studies focusing on the brick pavers, sod and rain gardens and their combinations. In our research, we intend to know how these LID control measures affect the warm water temperature separately and in combination.

The present paper has two sections. The first section focuses on the test setup, methods and process. We believe that they are as important as the test result in order to facilitate future related research. A controlled test has been designed and constructed to understand the thermal characteristics of LID strategies. The research is based on the assumption that the LID strategies can affect the thermally polluted stormwater runoff in some degree. The second section focuses on the collaborative work and contribution our group of landscape architecture has made to the research. The Green Infrastructure Laboratory (GIL) is a joint laboratory including the disciplines of Building Science, Biosystems Engineering, Horticulture, and Landscape Architecture. The team has tried to build a collaborative model on the thermal impact study in the laboratory. In this case, except for the benefit brought directly by the research outcomes to stormwater management, the overall research agenda also examines the potential of the collaboration between those disciplines above.

3 MATERIALS AND METHODS

3.1 Study area and summer temperature characteristics

Before the controlled test was designed and conducted in the laboratory, a study on a specific area was conducted to better understand the thermal impact in the built environment. The study area is Mobile, Alabama, it is at the west side of the head of Mobile Bay. Mobile county is home to Alabama state's only seaport, and the city of Mobile has developed through this seaport economy. The city of Mobile is also recognized by the rich water resource and multiple water ecosystems such as estuarine, freshwater, and marine. It brings various recreational fishing opportunities and commercial fishing industry (Mobile Area Chamber of Commerce, 2014). The water quality and habitat protection in delta, estuary, and bay area are the critical factors to maintain the fish population and biodiversity. Mobile Bay and its tributaries provide a wide array of important services for fish, crustaceans, and wildlife including nursery habitat for a period of their life cycles. Urbanization has changed the surface characteristics of Mobile. During a rainfall event, stormwater runoff carries the heat and distributes it into streams, rivers, lakes, and bays. The warmer stormwater runoff mixes and potentially increases base temperature, which will affect the thermally sensitive species or communities of receiving waters.

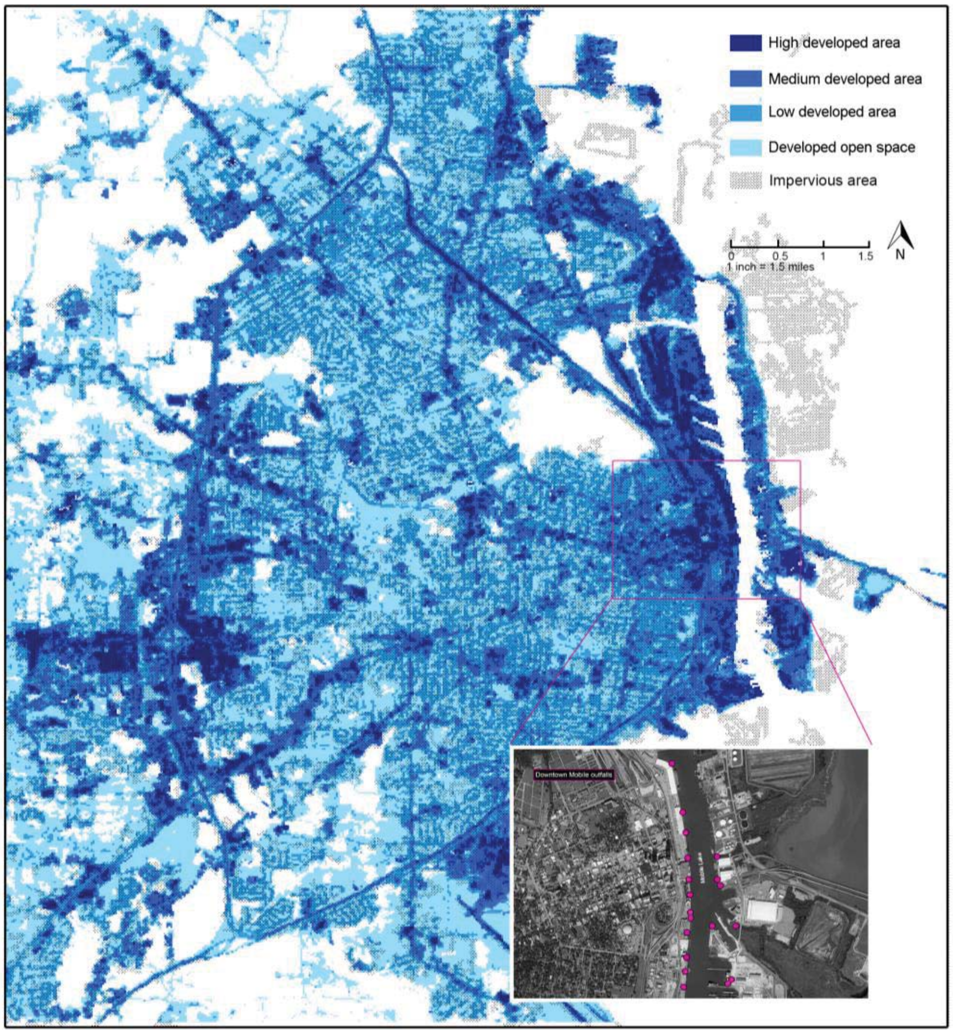

Figure 1. Developed area and imperviousness of Mobile (Figure by the authors)

It is recorded that over 90% developed area are imperviously constructed in the City of Mobile (Figure 1). Previous studies have shown that the higher the urban intensity or imperviousness, usually the higher the land surface temperature (Oke, 1973). The summers in Mobile are long and hot, and the winters are short and cold. Over the course of the year, the temperature typically varies from 42°F to 90°F and is rarely below 28°F or above 95°F. Although the recorded average temperature is not extremely high in summers, the peak temperature of day and direct sunlight can result in an even higher temperature effect to the specific urban surfaces. In some cases, the temperature of stormwater runoff (first inch of flow) flowing over heated impervious surfaces in downtown Mobile can be as high as 50°C during the month of July (Green Infra Lab, 2017). Warm water temperatures can affect aquatic systems and alter stream flow patterns (Poff et al., 1997), and it potentially affects fish species and aquatic organisms. For most fish, a 10°C increase in water temperature will approximately double the rate of physiological function (Di Santo & Bennett, 2011). Fish needs more oxygen at higher temperatures because of the increased respiration rates, which can be detrimental if rates remain raised for an extended period of time (Pearson Education, n.d.). However, most fish species are vulnerable when water temperature exceeds 34°C, because temperatures above 35°C can begin to denature, or breakdown, enzymes, reducing metabolic function.

3.2 Material use and experiment setup

The test had four phases (P1, P2, P3, P4). We tested several different samples separately and their combinations. The testing samples are pervious concrete (PC), impervious concrete (IC), sod, brick pavers with gravel joint (pervious paving approach for brick pavers in built environment), and rain gardens (Table 1). Four cells (C(a), C(b), C(c), C(d)) were constructed to hold the samples. Phase 1 and 2 focused on the impact of each sample to warm water temperature, and phase 3 and 4 focused on the impact of the combination of PC/IC, sod, bricks with rain gardens to warm water temperature. The combination test schedule implied our research scope. We realized that in the real environment, stormwater runoff flows through different LID practices at the same time during a rain event, and it is a complex process. Therefore, a combined impact of these LID practices is needed to be examined. In this case, at least one type of combination for the research would make more sense through the lens of landscape architecture. By testing the combination of LID practices, we are expected to understand complex landscape performance through thermal discourse.

Table 1. Test phase map (Table by the authors).

Cell	P1	P2	P3	P4
C(a)	IC	Sod	Sod – rain garden (a)	Sod – rain garden (b)
C(b)	PC	Brick pavers	Brick pavers – rain garden (a)	Brick pavers – rain garden (b)
C(c)	IC	IC	IC – rain garden (a)	IC – rain garden (b)
C(d)	PC	PC	PC – rain garden (a)	PC – rain garden (b)

This study required a series of equipment to acquire, monitor and analyze water temperature. The types of equipment and how they are used is critical to the research (Table 2). As mentioned above, four cells were designed and constructed to hold the samples as well as their appropriate installation components (base, and sub-base aggregates). The probes system, heating, and cooling system were attached to the samples in a specific way. Take phase 1 for example, two PC and two IC were placed in each cell with four heat lamps on the top separately. Each sample was associated with five probes recording the temperatures of different places. Three probes collected temperatures of surface, middle, and bottom of the samples separately. The fourth probe of each sample was in a pan designed for collecting artificial runoff. A fifth probe was left for phase 3 and 4 where rain gardens would be introduced. These temperature probes transferred temperature data at 1-minute interval to a datalogger where it connected a laptop for analyzing purpose.

Table 2. Equipment used in the research (Table by the authors).

Equipment	Model	Power	Use
Heat Lamp--Solaira Weatherproof Infrared Heater	Alpha HI	1.5kw/120V	Heating cycle
Sprinklers--Rainbird 8 Series (8Q) Plastic Rotator	1806	32 psi.	Cooling cycle
Probes/Data Logger—Roctest	\	\	Acquire temperature
SENSLOG Data Acquisition System	CR1000	\	Data analysis
FLIR Thermal Camera	T450sc	-20° C to 1500° C	Thermal imaging

The initial design of the cells was done by the students and professors from Building Science and Biosystems Engineering. The cell was 32” tall, and the concrete paving samples were 18” x 18” x 4”, weighing between seventy to one hundred twenty pounds each. All of the cells were constructed out of sturdy 2” x 12” pieces of lumber with 4” x 4” posts as legs. A room was also designed next to the samples for collecting “stormwater runoff” from the surface of the IC samples (Sample A and sample C), and each cell had holes at the bottom to transfer filtered “stormwater” to the pan (Figure 2).

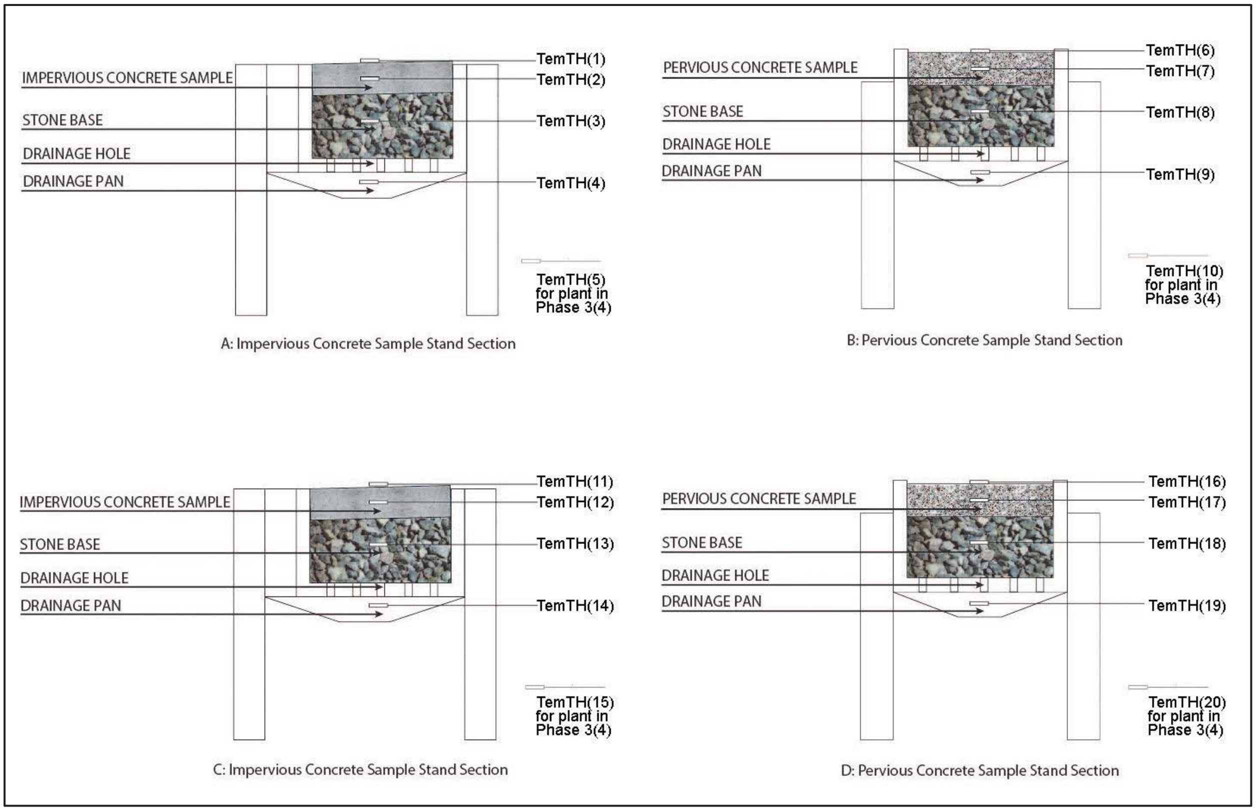

Figure 2. Phase1 samples and probes layout diagram (Figure by the authors)

3.3 Test procedure

A heating cycle and cooling cycle were designed for simulating the weather condition (rainwater and sunlight). The heat lamps simulated the natural sunlight, and the sprinkler system simulated the natural rain event. The concrete samples were initially held under heat lamps for approximately three or four hours in order to raise their temperatures to comparable levels found in pavements under intense summer sunlight (50°C - 70°C). Twenty sample events (replications) were recorded. The result showed that each place of the sample increased the temperature in some degree with different growing patterns. Following a four-hour heating cycle, the samples were sprayed with water (32 pound per square inch) from an irrigation system for one hour. During the test, water that either ran off (impervious) or infiltrated through the samples was collected in a pan bellow the stands. The phase 2 had one PC, one IC, brick pavers with gravel joint, and a sod sample. They then connected to rain gardens separately for phase 3 and 4 through a PVC pipe at the bottom pan of each sample cell. During the cooling period, artificial runoff was transferred to the plant component and was infiltrated through soil, finally flowed into another vessel with the fifth probe recording the temperature (Figure 3). Pretest showed that the sod and pervious brick paver samples heated up quickly than we expected. The PCs, ICs, pervious brick pavers, and sod have longer heating cycle than their cooling cycle. The PCs heat up faster than their impervious counterparts in a four-hour heating duration. This may be because of their higher porosity. However, the PCs also tend to cool down faster, giving up its stored thermal energy for the same reason it captures it so quickly.

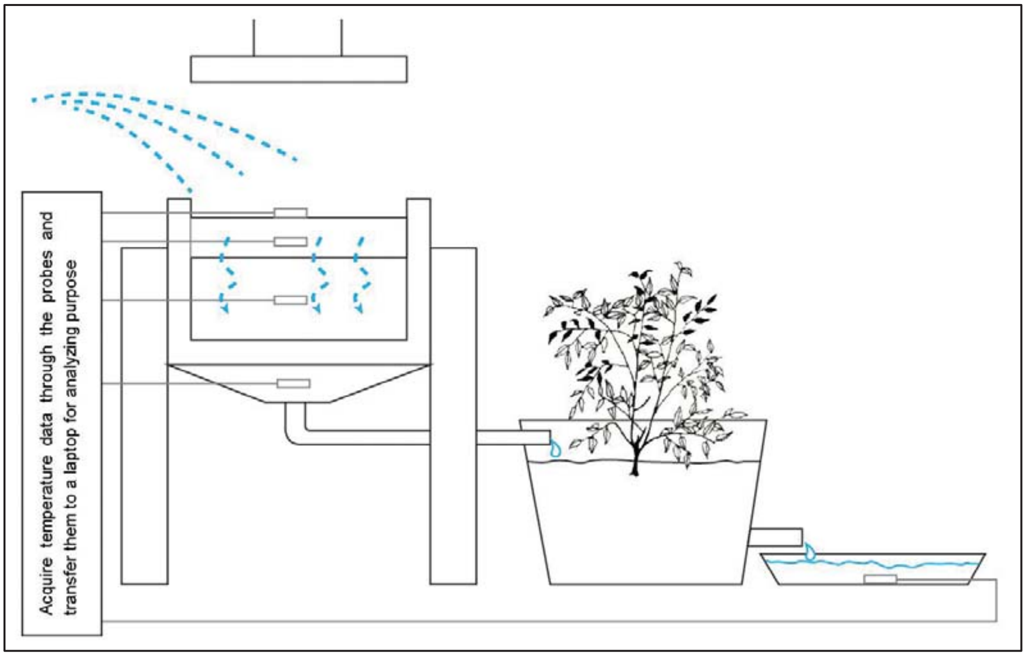

Figure 3. Phase 3 and 4 test setup and water flow diagram (Figure by the authors)

4 LANDSCAPE ARCHITECTURE INVOLVEMENT IN THE RESEARCH

The GIL was characterized by the interdisciplinary work. The research team included professors and graduate students from Building Science, Horticulture, Biosystems Engineering, and Landscape Architecture, which a dynamic research framework was expected to be established. In this section, we intend to present the major work the group of landscape architecture has contributed to the research, and how it helps to achieve a more validated and accurate research outcome. We summarize the research work into five categories: Design/update, Maintenance/craft, Materiality, Analysis/manipulation, and Outreach. And each type of work can be done by the lab, cell, test, and sample scale. A brief description for each category is presented to understand the type of work in detail:

- **Design/update:** The thinking process needed for every scale of work. we made agenda for the test running, cells' form and function, sample size and PC/IC mix configuration, laboratory layout, and test presentation. In addition, workflow was also designed before actual test implementation.

- **Maintenance/craft:** The making process in the construction, installation and replacement of cells, tests, and laboratory devices. The maintenance of the plant species, and other labor work needed for the research.

- **Materiality:** The preparation of the materials. We prepared aggregate and cement for PC/IC; gravel, soil for brick pavers and sod. The lumber, nail material for the stands and cells. The mulch, soil, and sand mix for the plant component.

- **Analysis/manipulation:** The implementation of the test. It included the connection of sensor devices with samples, actual running the cooling and heating cycle, collecting temperature data, and analyzing data.

- **Outreach:** The presentation of the research. Various approaches were used to bring the research process and findings to broader audience, such as video, website, handbook, and public demonstration.

Table 3. Collaboration matrix map.

Phase	Scale	Design/update	Maintenance/craft	Materiality	Analysis/manipulation	Outreach
	Lab	BS, BE	BS, BE, LA, HC	BS, BE, LA, HC	\	LA, HC
P1	Cell	BS, BE	BS, BE, LA	BS, BE	\	\
	Test	BS, BE, LA	BS, LA	\	BS, BE, LA	\
	Sample	BS, BE	BS	BE	BS, LA	\
	Lab	\	LA	BS, LA	\	LA
P2	Cell	LA, BS, BE	LA	BS, LA	\	\
	Test	LA	\	\	LA, HC	\
	Sample	LA	LA	LA, BS, HC	LA, HC	\
	Lab	BS, LA	BS, LA	\	\	LA
P3	Cell	LA	LA	LA	\	\
(P4)	Test	LA, BS	LA	LA	LA, HC	\
	Sample	HC	LA	HC, LA	LA, HC	\

*Note: BS—Building Science; BE—Biosystems Engineering; LA—Landscape Architecture; HC—Horticulture.

The responsibilities of LA have largely penetrated the research process. The collaboration matrix map also presents the responsibilities three other disciplines have had during the research (Table 3). BC and BE first dominated the test in phase 1 and then decreased in phase 2 and 3 (4); LA and HC started to participate more from phase 2 and 3 (4). The team had consent that this transition was predictable and reasonable. The samples we tested were from PC/IC to plant-oriented component through four phases (Table 1). Although we collaboratively work together, each discipline had its own research scope and goals. BE and BC focused more on the thermal nature of the concrete material, so they developed an initial test method for testing PC/IC. Horticulture focused more on the impact of warm stormwater to the plant root system. LA showed more interest on how PC/IC, brick pavers and rain gardens affected warm stormwater runoff for the urban settings. This gave the reason that why LA and HC intensively participated the test when plants were introduced. Our test setup and process accommodated all these intent within one test structure. It is fair to conclude that the research framework we designed allows each discipline to benefit from the test. It is also important to acknowledge that the collaboration matrix map aims to show the degree of the diversity of the work each discipline was involved in. It does not emphasize the degree of the importance of the work of each highlighted category. We believe that these categories are highly integrated and naturally combined for forming the research. To better understand our responsibilities, we summarize the work into two parts. The first part was about test-oriented work, which included the stands, plant maintenance, and the rainfall distribution test. The other part was about the test outreach, which included the visual communication and the media representation. A few examples are presented below to exhibit the contribution of LA to the research.

4.1 Stands maintenance

One of the test-oriented work was the stands maintenance, and it mainly happened in phase 1. In the GIL, decay occurred. Pretty much like in the exterior environment, the stands gradually rot when water met the wooden structures for a certain period of time. The degradation of the stands has potential to cause leak problem. Since the cooling cycle was one of the essential procedures which cannot be adjusted to avoid the degradation, it brought a concern on the use of the materials for building more appropriate cells and other associated construction elements. During phase 1, we suggested the use of water-proof paint for the wooden pieces for the updated stands. In addition, the design of the cells should take consideration of the sample's life cycle, weight, maintenance, and replacement. Due to the different porosity rates, the concrete samples weighed seventy to one hundred twenty pounds. One the one hand, they were very heavy to be moved in and out of the cells when the samples needed to be replaced. On the other hand, heavy samples may cause the crash of the cells if the load was not calculated in advance. To ensure the cells to hold the samples firmly, we added two metal brackets for each cell, and initiated a design activity for a movable and modular stand.

4.2 Plant maintenance

As the sod sample started to be introduced in phase 2, the plant component has become another part that needed a careful maintenance. We provided the plant with the adequate light, moisture, and nutrients, and most of the plant components grow well in the indoor environment. However, the sod sample showed the different growth conditions. The grass in the edge grew faster than the grass in the center. It was because the sod sample was 18" x 18", and the heat lamp was 18"x10", which the sod sample was not fully covered by the heat lamp. When the heat lamp turned on, the center part of the sod sample was exposed to the stronger heat energy than the extra part.

In addition, one of ink berry (Ilex glabra) shrubs died during the phase 3. We found that it was affected by the spider mite (Tetrany chidae), which was a type of arachnid sticking on the leaves. By applying the pesticide on the leaves, the spider mite was removed from other three ink berry shrubs. A new ink berry was planted as well. However, the pesticide has become an unknown factor that may impact the test result. We decided that all the ink berry shrubs should be replaced by a new batch of plants. In phase 4, we kept inkberry species, and added two more plant species into each plant pot. Mixed plant combination can better simulate the rain garden conditions than the single species. These three species were selected based on Low Impact Development Handbook for the State of Alabama (Katie L. Dylewski, Jessica T. R. Brown, Charlene M. LeBleu, & Eve F. Brantley, n.d.) by the professor from the Department of Horticulture. Southern wax myrtle, dwarf yaupon holly, and inkberry holly are the common shrubs for rain gardens and bioretention in Alabama, and relatively easy to maintain in the indoor environment. So they are suitable for our research at this stage.

Table 4. Plants in Phase 4 (Table by the authors).

Common name	Southern Waxmyrtle	Dwarf Yaupon Holly	Inkberry Holly
Scientific name	Morella cerifera	Ilex vomitoria 'Schilling's Dwarf'	Ilex glabra 'Shamrock'
Growth habit	15 - 20' H x 15 - 20' W	4 - 6' H x 6 - 8' W	3 - 4' H x 3 - 4' W
Light Req.	Full Sun to Part Shade	Part Sun to Part Shade	Full Sun to Part Shade
Moisture Req.	Medium to Wet	Dry to Wet	Medium to Wet
Hardiness Zone	Zone 7 - 10	Zone 7 - 10	Zone 4 - 9
Characteristics	Wet & Drought Tolerant	Salt & Drought Tolerant	Wet Tolerant

4.3 Rainfall distribution uniformity test

The cooling system is critical to the test, non-uniform rainfall distribution may cause the ineffective test result. To improve the accuracy of the test, we did a supplemental test to see if the "rainfall" was occurring uniformly across four samples. During the test, four containers were placed on the four corners of each sample, and a thirty-minute spraying from cooling system was applied to the sample and the containers. Then "rainfall" collected by sixteen containers were measured by a measuring cylinder. The result for each sample was illustrated as four blue bars. They showed the volumes of "rainfall" collected in each container. The overall distribution uniformity rate was seventy-seven percentage. By analyzing the "rainfall" distribution area of each sample, the red-dot area showed the highest uniform distribution rate in the test model (Figure 4). This result revealed that a better test may be improved by clustering the sample stands at the center of the irrigation system.

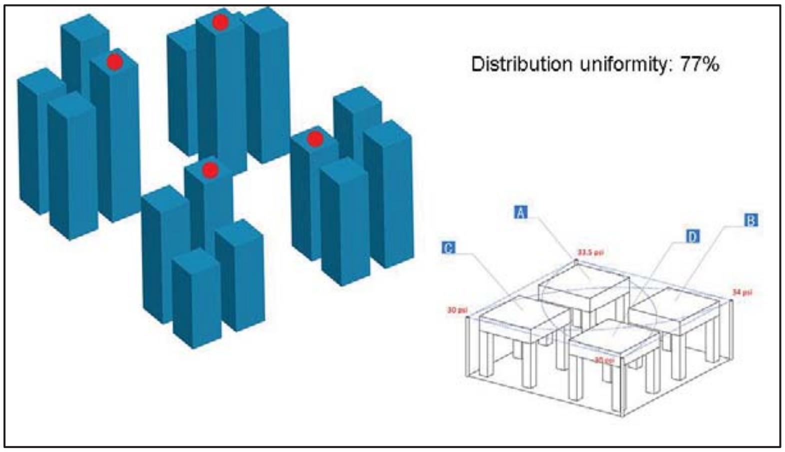

Figure 4. Rainfall distribution uniformity test (Figure by the authors)

4.4 Data visualization

To better present the research analysis and result, we tried to make the test data visually friendly. The exploration on the visual presentation of data by researchers and designers is not new. This approach manages data in such a way that viewers can visually communicates with data, making viewers quickly draw the information from a set of numeric data. To make the test result readable, data visualization is needed for our research. Since real time temperature data was collected by twenty probes, data analysis software generated the line graph that one line stood for one probe. In phase 1 and 2 there were 16 lines separately showed the temperature change, and 20 lines in phase 3 and 4 separately showed the temperature change. The overlay of these lines made the certain parts of the result not perfectly readable. In this case, we tried to redesign the graph and made it more readable. However, we found it very difficult to show the temperature within the sample itself and temperature change across the different samples in one graph. For instance, we illustrated the temperature change of the surface, middle, and bottom of each sample by using four graphs, but the graphs failed to illustrate the temperature relationship of the same location across different samples (Figure 5). Because the research has not been completed, data visualization at this stage is an ongoing process, as it needs the iterations and refinement to find the better approach to describe the result.

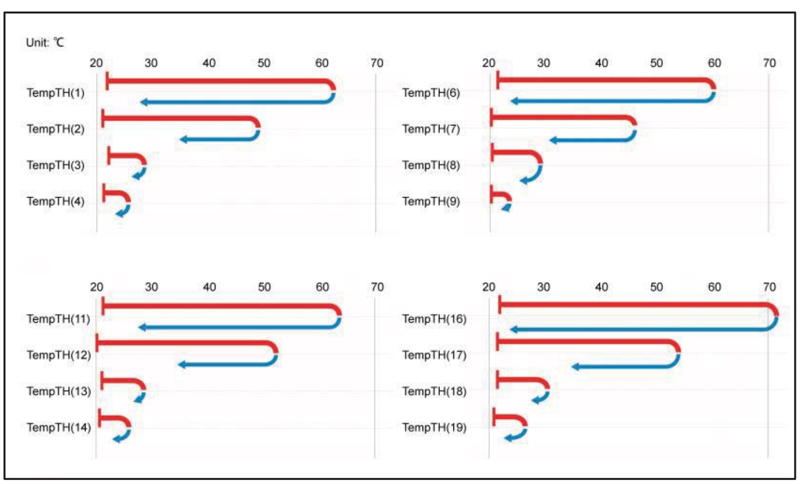

Figure 5. Data visualization example (Figure by the graduate assistant Britton Garrett)

4.5 Media representation

It is important to use multiple medium to facilitate this collaborative research. We believe that the value of this research not only lies in the test result, but also can be credited by the collaboration. The team intended to spread our collaborative work form to broader audience, which can make dynamic conservations happen in and out of the laboratory. In this case, we tried various approaches to disseminate our thermal impact study. For instance, a "How to book" with text and photos was created to introduce the research basis, share the specific test language and described the test steps and methods. By reading this we can minimize the impact caused by the individuals' experiment manner to the test, which helped to maintain the test quality and improve work efficiency for different testers from different disciplines. It can also be a good medium for spreading our research when we interact with different groups in and out of the GIL. A website was established to exhibit the research progress, archive test events and laboratory documents. It also had the function which we can receive comments or feedback from the public. In addition, a three-minute video was filmed and incorporated in the website. It described the test setup, methods, objectives, and importance of the research. The video showed the experiment devices, heating and cooling system, and the laboratory environment, which gave viewers a more tangible picture of the research context.

In conclusion, Landscape Architecture has largely involved in this thermal impact research through multiple perspectives, and we have had many findings throughout our work. From the test-oriented perspective, we have found that the sod sample is more sensitive to the heat, and requires more maintenance and replacement than the PCs, ICs, and brick pavers. The cells should change to a water-proofed and lightweight material that properly accommodate the samples. From the outreach perspective, data visualization and media representation help to disseminate the interdisciplinary research, which opens the opportunity of the conversations and interactions. From the collaboration perspective, there is no reason for a collaborative team not to have varying research scope. Varying research scope is acceptable and welcome if the team can strategically make research framework for each discipline's good.

5 CONCLUSION

Urbanization and climate change have changed hydrological cycle and ecosystem. In the urban settings, stormwater runoff heated by hard surfaces in summer flows into the receiving waters, potentially affects the aquatic life. LID practice is a common approach to address the urban stormwater issue. To find out how LID practice can affect the stormwater temperature, we set up a laboratory test in the GIL at Auburn University. An interdisciplinary team was also established for this research, as four disciplines collaboratively work together with different points of the focuses and scope. The ultimate goal of the research is to find out how LID practice affects water temperature. Besides this, we believe that the test setup, research methods and process are also critical for achieving a favorable research outcome, as it can help us to see the difficulties and opportunities embodied in the research. What is more, it provides a basis for related future research. This paper also discusses the collaboration pattern and highlights the role of landscape architecture in the interdisciplinary team in a laboratory working environment. This complex thermal impact issue requires the collaboration across different disciplines, where landscape architecture can offer the ability to synthesize and visualize complex data, a familiarity in construction and craft process, and skills in stimulating the conversations between teams and public (Ahern, Leduc, York, & Foundation, 2007). Moreover, this interdisciplinary team builds a unique working model in the laboratory scale. Through "To learn by doing", landscape architecture obtains the opportunity to move out from the "comfort zone", tries to expand research boundaries and understands complex landscape performance of LID practices through the thermal aspect rather than the application perspectives.

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