National Center for Sustainable Transportation
A USDOT University Transportation Center

Research Report

January 2025

Mitigating Extreme Heat Exposure Using Advanced and Novel Materials and Improved Pedestrian Infrastructure Design

A Systematic Literature Review and Survey of Agencies

Elizabeth M. B. Doran, University of Vermont
Will Reichard, Georgia Institute of Technology
Morgan Boothe, University of Vermont
Grace Donnell, Georgia Institute of Technology
Huiying Fan, Georgia Institute of Technology
Gregory Rowangould, University of Vermont
Randall Guensler, Georgia Institute of Technology

THE UNIVERSITY OF VERMONT TRANSPORTATION RESEARCH CENTER

Georgia Tech School of Civil and Environmental Enginee
College of Engineering

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NCST-UVM-RR-25-02	N/A	N/A

4. Title and Subtitle Mitigating Extreme Heat Exposure Using Advanced and Novel Materials and Improved Pedestrian Infrastructure Design: A Systematic Literature Review and Survey of Agencies	**5. Report Date** January 2025 **6. Performing Organization Code** N/A
7. Author(s) Elizabeth M. B. Doran, Ph.D., https://orcid.org/0000-0001-9307-4516 Will Reichard, https://orcid.org/0000-0002-3401-1424 Morgan Boothe, https://orcid.org/0009-0006-1059-2726 Grace Donnell, https://orcid.org/0009-0002-0718-0027 Huiying Fan, Ph.D., https://orcid.org/0000-0002-0351-386X Gregory Rowangould, Ph.D., https://orcid.org/0000-0003-3315-5028 Randall Guensler, Ph.D., https://orcid.org/0000-0003-2204-7427	**8. Performing Organization Report No.** N/A
9. Performing Organization Name and Address University of Vermont Transportation Research Center College of Engineering and Mathematical Sciences 33 Colchester Ave, Burlington, VT 05405 Georgia Institute of Technology School of Civil and Environmental Engineering 790 Atlantic Drive, Atlanta, GA 30332-0355	**10. Work Unit No.** N/A **11. Contract or Grant No.** USDOT Grant 69A3551747114
12. Sponsoring Agency Name and Address U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology 1200 New Jersey Avenue, SE, Washington, DC 20590	**13. Type of Report and Period Covered** Final Research Report (September 2022 – August 2023) **14. Sponsoring Agency Code** USDOT OST-R

15. Supplementary Notes
DOI: https://doi.org/10.7922/G23J3BBH
Dataset DOI: https://zenodo.org/records/14018709

16. Abstract
Extreme heat is the leading cause of weather-related mortality in the United States, and extreme heat events are projected to continue to increase in geographic extent, frequency, and severity in the United States as climate change progresses. Transportation infrastructure is a significant driver of the urban heat island (UHI) effect and exacerbating extreme heat events. Efforts to mitigate UHI impacts often focus on reflecting incoming solar radiation (i.e., increasing surface albedo) and providing shade (e.g., planting street trees). However, advanced and novel materials (ANM) for pavements that reduce heat storage, and green stormwater infrastructure (GSI) that promotes evaporative cooling, can provide additional heat mitigation pathways. Sidewalks facilitate non-motorized transportation, and are relatively low-risk, low-cost, and have simple structural requirements compared to other transportation infrastructure. Hence, sidewalks and adjacent planting strips can offer a logical test bed for new materials and designs. With the thermal comfort, safety, and efficiency of users in mind, environmentally responsible designs can also minimize energy embedded in construction materials and help maintain natural ecosystem processes. Although ANMs hold significant promise for heat mitigation, they have not yet achieved widespread implementation. This project systematically reviewed the growing literature related to the application of ANMs and GSI to reduce UHI effects and implemented a survey of urban planners and public works engineers to assess the current and planned use of these strategies and identify barriers to implementation. This report summarizes the emergent themes from the systematic literature review, survey results and policy recommendations for an anticipated reading audience of urban policy makers, planners, and practitioners.

17. Key Words	18. Distribution Statement
Urban heat island, green stormwater infrastructure, advanced pavements, alternative pavements, cool pavements, novel materials, decision-making, transportation planning, thermal comfort	No restrictions.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	78	N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

NCST

ABOUT THE NATIONAL CENTER FOR SUSTAINABLE TRANSPORTATION

The National Center for Sustainable Transportation is a consortium of leading universities committed to advancing an environmentally sustainable transportation system through cutting-edge research, direct policy engagement, and education of our future leaders. Consortium members include: the University of California, Davis; California State University, Long Beach; Georgia Institute of Technology; Texas Southern University; the University of California, Riverside; the University of Southern California; and the University of Vermont. More information can be found at: ncst.ucdavis.edu.

Disclaimer

Acknowledgments

This study was funded, partially or entirely, by a grant from the National Center for Sustainable Transportation (NCST), supported by the U.S. Department of Transportation (USDOT) through the University Transportation Centers program. The authors would like to thank the NCST and the USDOT for their support of university-based research in transportation, and especially for the funding provided in support of this project. Additional thanks go to the undergraduate research assistants at both the University of Vermont and the Georgia Institute of Technology for their dedication and professionalism in collecting data, and recruiting survey participants. Finally, a thanks to the peer reviewers of this report who provided thorough and thoughtful feedback on the first draft.

Mitigating Extreme Heat Exposure Using Advanced and Novel Materials and Improved Pedestrian Infrastructure Design

A Systematic Literature Review and Survey of Agencies

A National Center for Sustainable Transportation Research Report

Dr. Elizabeth M. B. Doran, Civil and Environmental Engineering, University of Vermont

Will Reichard, School of Civil and Environmental Engineering, Georgia Institute of Technology

Morgan Boothe, Civil and Environmental Engineering, University of Vermont

Grace Donnell, School of Civil and Environmental Engineering, Georgia Institute of Technology

Dr. Huiying Fan, School of Civil and Environmental Engineering, Georgia Institute of Technology

Dr. Gregory Rowangould, Civil and Environmental Engineering, University of Vermont

Dr. Randall Guensler, School of Civil and Environmental Engineering, Georgia Institute of Technology

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Mitigating Extreme Heat Exposure Using Advanced and Novel Materials and Improved Pedestrian Infrastructure Design

A Systematic Literature Review and Survey of Agencies

EXECUTIVE SUMMARY

Extreme heat is the leading cause of weather-related mortality in the United States, and climate change will continue to increase the frequency, geographic extent, and severity of extreme heat events over time. In urban environments, the presence of anthropogenic building materials and activity and the loss of native vegetation and evapotranspiration processes causes urban areas to be warmer than their rural surroundings, a phenomenon known as the urban heat island (UHI) effect. Transportation infrastructure is a significant driver of the urban heat island (UHI) effect and the creation of extreme heat micro-environments, including in smaller cities and towns. Current efforts to mitigate UHI effects tend to focus on reflecting incoming solar radiation (i.e., increasing surface albedo with, for example, reflective pavements) and providing shade (e.g., planting street trees). However, additional heat mitigation pathways are offered by advanced and novel materials (ANM) for pavements, designed to reduce heat storage, and the implementation of green stormwater infrastructure (GSI) solutions that promote evaporative cooling. With pedestrian thermal comfort, safety, and efficiency for users in mind, environmentally responsible designs can also minimize material-embedded energy and maintain natural ecosystems and processes. Although ANM and GSI mitigation strategies hold significant promise, neither have achieved widespread implementation in pedestrian infrastructure. Sidewalks facilitate non-motorized transportation, and are relatively low-risk, low-cost, and have simple structural requirements compared to other transportation infrastructure. Hence, pedestrian infrastructure offers a logical test bed for these new materials and designs. This project reviews the growing literature related to the application of ANMs and GSI to reduce UHI impacts. The team then implemented a survey of planners and public works engineers to assess the role of these alternatives in current pedestrian infrastructure plans and to identify potential barriers to implementation. This report summarizes the survey methods, survey results, findings related to selection of mitigation alternatives, and respondent-reported issues associated with implementation (regulatory requirements, design standards, economic feasibility, etc.) for an anticipated reading audience of urban policy makers, planners, and practitioners.

Based on the reviewed literature which was constrained to studies published between 2019 and 2023, some material components such as novel aggregates including glass show promising results in laboratory experiments, suggesting a TRL 3-4; however, additional materials such as permeable pavements are likely at TRL 7-8. For materials and designs

that are at higher levels of technology readiness, further evaluation across both efficacy, durability and maintenance would be required to characterize the materials as fully ready for widespread adoption (TRL9) and while evident, this information was also the most limited within the reviewed literature. Furthermore, evaluation of the emissions impacts over the full lifecycle was limited.

Results of the survey of transportation planners and engineers working in Northeast and Southeast US communities suggest that while there is general awareness of advanced and paving materials and designs, adoption by practitioners is low by comparison. The primary motivation for practitioners who did report adoption was stormwater related. In fact, urban heat reduction was reported as an explicit goal within the organization by just 7% of respondents and did not reflect regional climatic differences. This, combined with low levels of concern about extreme heat by respondents, suggests a decisional gap in understanding the impact of heat on vulnerable populations including small children and older adults. This gap may be addressed through regulatory and funding incentives. Additional research to test this theory and evaluate the impact of these barriers relative to regional climatological differences and risks. General satisfaction was noted across respondents who had experience with implemented novel materials and alternative designs, despite some reports of increased maintenance and lower durability compared to traditional materials. Some skepticism was also evident as to the efficacy across design and operational criteria suggesting more research to demonstrate efficacy of in situ projects is needed.

Because respondents who were aware of alternative materials and designs were often aware of multiple options, decision-support tools that allow practitioners to evaluate design and criteria tradeoffs are needed and evidence of such tools was present within the reviewed literature. However, evaluation of the efficacy and adoption of such tools, being outside the scope of this study, is needed, particularly in the context of municipal capacity which can vary significantly across communities.

CHAPTER 1. INTRODUCTION

Extreme heat is, and has been for the last 30 years, the leading cause of weather-related mortality in the United States (*1*–*3*). In fact, heat exposure takes more lives than all other weather-related hazards combined (*3*). Current research suggests that extreme heat will continue to increase in frequency under climate change (*4*) and result in worsening impacts to health and wellbeing (*5*, *6*). Exposure to extreme heat can cause increased discomfort and fatigue, while increased heat exposure can lead to heat cramps, heat exhaustion, and heat stroke; increasing the number of emergency room visits and hospitalizations and exacerbating underlying conditions. While some acclimatization is possible, physiological limits exist but are poorly understood (*7*, *8*). Before those limits are reached, high temperatures and exposure that causes discomfort and fatigue can be enough to deter people from engaging in outdoor activities and active travel (*6*). These factors must therefore be considered during the design of transportation infrastructure including public transportation, sidewalks and bike lanes, and in making last mile connections.

1.1 Urban Heat Islands: Characteristics and Impacts

At the city scale, it is well understood that urban areas are typically warmer than their surrounding rural environs, a phenomenon known as the urban heat island (UHI) effect. UHIs have been observed repeatedly in urban centers of all sizes around the world since the beginning of the modern era of scientific observation (*9*–*11*). Under warming climate conditions, these temperature anomalies can mean the difference in extreme heat exposure and duration. UHIs can form during the day or night, and in any season. There are three main types of urban heat islands (see Figure 1): boundary layer urban heat islands which form in the lower atmosphere (BLUHIs, Figure 1a), canopy layer urban heat islands which form between the ground and tree or building height where people most acutely experience local climate conditions (CLUHI, Figure 1b), and surface urban heat islands which are comprised of surface temperature differences that can be observed using remote sensing platforms (SUHI, Figure 1c). Each type has specific impacts that hold management implications for transportation professionals.

The atmospheric UHIs measure air temperature anomalies at two levels. The planetary boundary layer, or lower atmosphere (Figure 1a), which can extend multiple kilometers above the ground, is where the urban heat plume is found, extending downwind from the driving urban center over adjacent rural areas (*10*, *12*). One recent study found this plume can extend between 40 and 70 kilometers downwind in the case of Chicago (*10*, *13*). At regional scales and in higher levels of the atmosphere, this variable warming can create uplift and atmospheric mixing that can result in, for example, patterns of concentrated rainfall and localized flooding (*14*).

The canopy layer heat island (CLUHI) is measured between the ground and building height (Figure 1b), and is the one experienced as individuals move around their environment either by active travel, recreation or in making last mile connections. CLUHIs are typically measured using both high quality and informal air temperature instruments mounted at approximately two meters above ground level (*12, 15*). For reference, a typical adult male has a center of mass at approximately 1.5 meters above ground level, so thermal comfort studies often use this height instead. Additional physical parameters such as relative humidity, wind speed, cloud cover and sky view factor may also be measured. At local scales, and at ground level, CLUHI air temperatures on a warm day can vary as much as 20 degrees Fahrenheit over short distances such as from one city block to the next (*16*).

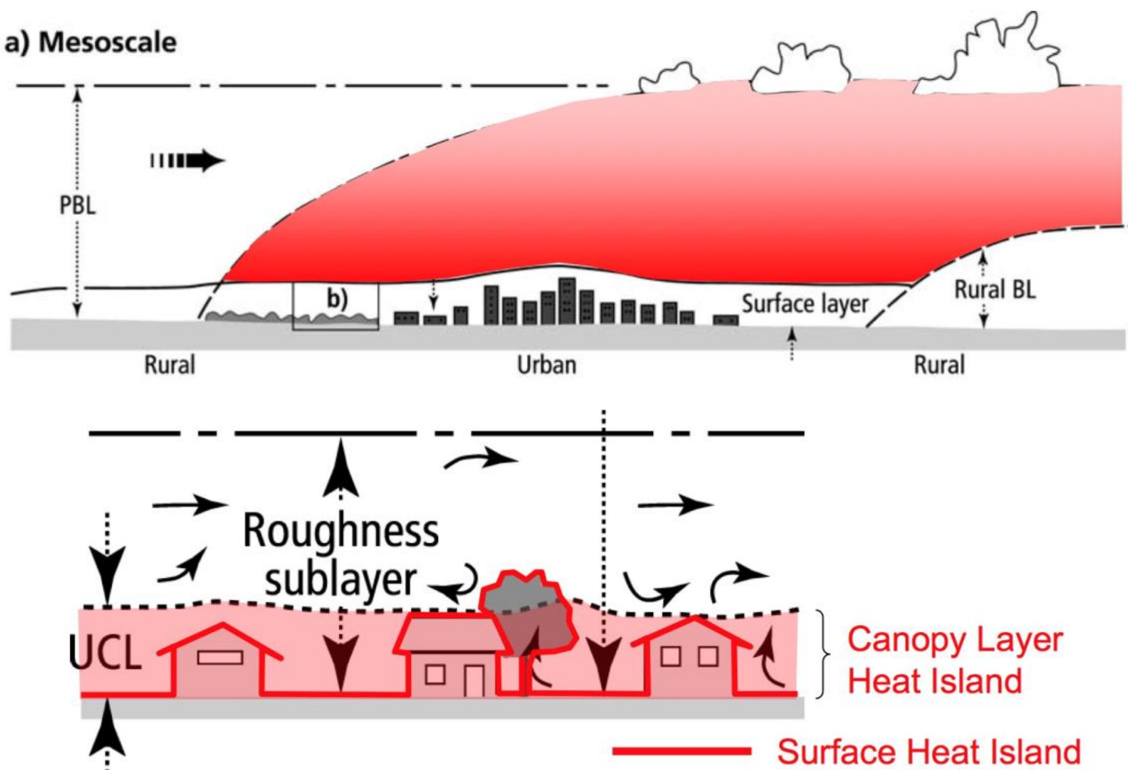

Figure 1. Three types of urban heat islands, a) planetary boundary layer UHI (top panel), b) canopy layer UHI (bottom panel red shading), and c) surface UHI (bottom panel red line). Modified from Voogt; Oke 1997.

Surface urban heat islands (SUHIs) capture thermal anomalies in the temperature of surface materials measured most often using remote sensing instruments including satellites. SUHI effects are most intense during the summer and are present throughout the day and the night, although temperature differences are more extreme during the daytime when materials are reaching their maximum thermal capacity (*17*). Because only some of the energy transiently captured in surface materials is thermally transferred to the low atmosphere and because of mixing and convection losses, SUHI intensity tends to be significantly larger than CLUHI intensity, over estimating air temperature differences.

However, SUHIs do drive energy radiation which, in addition to air temperatures, can significantly affect thermal comfort and increase the need for shade under some climate conditions (*18*).

The heterogeneity of the built environment including complex material composition and variable geometries interacting with natural materials and land covers contributes to the thermodynamic processes that create these heat micro-environment patterns. There are four primary factors driving UHI formation: 1) presence of impervious surfaces, especially asphalt, that have low reflectivity (low albedo); 2) lack of vegetation and reduced evapotranspiration potential; 3) release of anthropogenic heat from urban activity; and 4) urban geometric design that can trap heat in the urban area (*17*). Of the four UHI control factors, large surface areas composed of concrete and asphalt for transportation dominate the effect, due to their relatively low reflectivity and high thermal absorption capacity (*19*, *20*). However, anthropogenic sources of heat emitted from, for example, energy use in buildings, vehicles, and air conditioning also contribute significantly to UHI formation and are increasing over time (*21*). UHI effects are further exacerbated by current urban design standards, where tall buildings tend to reduce urban ventilation and trap heat within the urban core (*19*).

In addition to increased exposure to extreme heat within urban centers, UHIs can also negatively impact air and water quality, energy consumption and greenhouse gas emissions from material consumption. For example, urbanization and landscape changes negatively impact local watersheds by limiting infiltration capacity, groundwater recharge, and evapotranspiration rates, while simultaneously increasing runoff (*17*). Research from China, indicates that large urban agglomerations can result in significant atmospheric drying, called Urban Dry Islands (*22*). Because the process of water evaporation requires a significant amount of energy which is then transferred out of the system through atmospheric uplift, the loss of evaporative potential can result in hotter urban atmospheric temperatures. Meanwhile, increased runoff either by overland flow or via stormwater conveyance, requires additional construction of green and gray water infrastructure to prevent urban flooding and control water quality from pollutants. At the same time, heat trapped in paved surfaces can also increase stormwater temperatures, causing thermal pollution in the surrounding water bodies (*17*). One recent study shows a linear relationship between impervious surface cover and urban stream temperatures, with a 0.008 °C rise for each 1% increase in impervious surface area (*17*).

Warmer temperatures accelerate the chemical reactions that result in smog and ozone formation. Particularly on transportation corridors, these increased pollutant levels can become trapped in urban canyons and by the urban canopy increasing exposure for pedestrians and nearby residents (*23*, *24*). Research further indicates that UHIs increase peak and total electricity demand, increasing the city's ecological footprint (*21*). Higher ambient temperatures lead to an increased energy demand in commercial and residential areas alike, which can double energy consumption in cities during peak solar periods (*17*). The increased energy demand contributes to increased greenhouse gas and other emissions production, water consumption, and waste generation as cities consume energy to provide cooling to residents (*17*), further exacerbating climate change and energy system impacts.

Since the 1980's, accelerated urbanization has drastically increased the percentage of urban land covered by impervious surfaces (*25–27*) , resulting in urban environments where up to 40 percent of land cover can be comprised of paved surfaces (*28*). Even in small cities and rural towns, paved surfaces follow the population and create heat micro-environments that disproportionally impact vulnerable and disadvantaged segments of the population (*11*, *16*, *29*, *30*). Roughly 75-80 precent of those paved surfaces are black asphalt (*28*) with the balance most often concrete. Dark surfaces such as black asphalt absorb more of the incoming solar radiation and get hotter during daytime heating cycles, releasing that energy at night and contributing to warmer urban air temperatures. The production of these materials is also a significant contributor to global greenhouse gas emissions, the primary driver of increasing global temperatures (*4*, *31*). Cement production, a key ingredient in concrete, for instance, accounts for eight percent of global greenhouse gas emissions (*32*), while asphalt likely generates about half again as much emissions (*33*).

As cities continue to grow (*25*), and urban infrastructure is renewed, opportunities to improve infrastructure design will continue to present themselves. Sustainable transportation infrastructure must therefore seek to meet multi-objective design requirements that include the safety and experience of users under both current and future climate conditions; that minimize the impacts of building, operating, maintaining and disposing of the infrastructure itself; and that are cost effective over the lifecycle including both capital and annual operation and maintenance expenditures.

1.2 Advanced and Novel Pavement Materials: Characteristics and Efficacy

UHI formation is generally understood to result from the introduction of the anthropogenic materials that make up the built environment and the removal of natural land covers and compositions (*10*, *34*). Anthropogenic materials have different thermodynamic properties including lower albedo, lower evapotranspiration potential and higher thermal storage capacity and emissivity (*35*). Pavement technology that seeks to minimize these differences in thermodynamic properties are often called *cool pavements* (*35–38*). The two primary pathways by which cool pavements seek to reduce UHI signatures are (a) increasing reflection or surface albedo, and (b) increasing the evaporative potential by increasing permeability (*36*). Materials that reduce the thermal storage capacity or shift the thermal inertia are relatively understudied.

Reflective pavements include the family of pavements designed to achieve UHI mitigation by increasing the reflectivity (surface albedo) of the pavement. Increased reflectivity can be achieved through several pathways: 1) using high-albedo concrete and asphalt, 2) applying reflective coatings to the surface of concrete and asphalt, 3) “white topping” existing pavements with a layer of more reflective material, and 4) layering loose materials like gravel or crushed stone for pathways (*37*). Permeable pavements employ materials that absorb water (e.g., porous asphalt, pervious concrete, permeable interlocking pavers, vegetative pavements, etc.) and subsequently provide evaporative cooling effects (*39*).

Despite the benefits of cool pavements, researchers have noted certain limitations. While reflective pavements do reduce the surface temperature for pavements, they also tend to increase the temperature of nearby buildings because more solar radiation is reflected from the pavement surface onto the buildings, especially during the summer time. Studies have shown that the cooling benefits derived from cool pavements are typically greater than the induced cooling costs for buildings (*39*). With respect to providing cooling for pedestrians, some studies have noted potentially concerning impacts of increased pedestrian heat stress associated with more reflective paving materials during high-intensity solar periods of the day (*40*).

Voids present in rough and porous surfaces allow water to permeate through the material and dissipate thermal energy more effectively than smooth surfaces, and can help to mitigate heat retention (*17*, *36*). Novel paving systems include porous bricks, open-joint bricks, open paving patterns, grass-concrete pavers while pathway materials might include gravel, stone aggregate, shells, woodchips, pine bark (*41*). However, as porous surfaces deteriorate, they can accumulate fines and debris in the surface voids, potentially reducing thermal conductivity over time and requiring additional maintenance compared to traditional, impervious materials. Full lifecycle assessment is required to evaluate the impact of this deterioration over time.

Compared to dense pavements, permeable pavements have higher porosity and is thus more prone to clogging (*42*). The cost of cool pavement solutions can vary significantly. While light-colored surfaces require little or no additional cost compared to conventional pavements, vegetative pavements can be a lot more expensive (*43*). While the lifecycle cost of cool pavements is not prohibitively high, the duration and complexity of construction may be discouraging agencies from implementing cool pavement solutions (*39*). Perception is another barrier, as agency pavement managers often perceive advanced or cooler pavements as a higher-cost solution that comes with additional performance risk (*44*). Lifecycle analyses across alternatives would be necessary to properly account for these complexities.

1.3 Green Stormwater Infrastructure: Characteristics and Efficacy

Permeable pavements that promote hydrodynamic exchange are one of a larger complex of stormwater solutions that leverage natural processes to treat and manage urban stormwater. Stormwater control measures (SCMs) are strategies to reduce the impacts of stormwater runoff, especially in urban areas. Urban areas traditionally use gray water infrastructure (curbs, gutters, paved channels, etc.) to manage stormwater and divert runoff away from the built environment. However, gray water infrastructure generally provides very limited storage and infiltration capacity (*45*). Concrete-based systems also contain significant embedded energy and costs that make them less sustainable than more innovative alternatives. One category of SCMs is green stormwater infrastructure (GSI), which includes vegetation-oriented solutions to mitigate stormwater runoff, such as rain gardens, bioswales, and green roofs. In recent years, GSI has become an increasingly prominent topic of research and discussion. SCM implementation varies widely across geographic areas, cities, and local ecosystem features. Perhaps the relatively recent emergence of GSI strategies has resulted in uneven adoption across cities that share similar geographic and economic conditions; however, some argue that the lack of local expertise in constructing and maintaining GSI systems coupled with the additional upfront expenses for design, implementation, and maintenance of these living systems are at the root of the variability (*46*).

GSI implementation provides numerous environmental benefits. These natural systems can help mitigate habitat loss and fragmentation caused by urbanization (*47*). GSI designs also serve to reduce the impact of storm surges, control runoff, and mitigate UHI effects through evapotranspiration, all of which help protect local habitats. GSI projects may also contribute indirectly to human health benefits by providing public space that encourages outdoor activity and exercise, thereby improving cardiovascular health, lowering stress, enhancing mental health, decreasing birth defect rates, and potentially decreasing crime and antisocial behavior (*48*).

Despite the challenges associated with development of local design and maintenance expertise for GSI strategies, GSI remains a promising tool for UHI mitigation given the supplemental positive impacts on human health and the environment. Because GSI strategies are generally implemented in public space, within which humans move and interact (e.g., parks, schools, sidewalks, paths, etc.), GSI designs can improve thermal comfort and provide substantial indirect human health and ecosystem benefits. GSI strategies may also provide much higher lifecycle cost effectiveness over traditional greywater infrastructure construction and maintenance, but additional research and case study assessment in this area is needed.

The goal of the systematic review summarized in Chapter 2 is to understand the state of the existing science of these advanced materials and alternative designs. In Chapter 3 we assess the state of practitioner awareness and implementation of alternative technologies as well as motivation and barriers. The findings summarized in this report are intended to be solutions oriented and to guide implementation and action to build resilient infrastructure at the scale and speed needed to adopt urban environments to changing environmental conditions so they can continue to serve and protect people and the planet.

CHAPTER 2. SYSTEMATIC LITERATURE REVIEW

2.1 Systematic Literature Review Methodology

To better understand the state of the science as it relates to advanced and novel paving materials and alternative designs to reduce UHI, specifically in the context of transportation infrastructure including sidewalk materials and design, a systematic literature review was conducted and is reported here using standard methods (*49*, *50*).

2.1.1 Problem Statement

Transportation infrastructure is a significant driver of UHI and extreme heat micro-environments (*11*), including in smaller cities and towns as demonstrated by recent mapping campaigns (*16*) and recent research including that conducted by the authors of this report. Efforts to mitigate UHI often focus on reflecting solar radiation (e.g., increasing surface albedo using reflective paints) and shading (e.g., planting street trees); however, advanced and novel paving materials (ANM) and designs that reduce heat storage potential or green stormwater infrastructure (GSI) that promotes evaporative cooling offer additional heat mitigation pathways. While some transportation infrastructure is subject to more rigorous design standards, sidewalks, which facilitate non-motorized transportation, represent a form of transportation infrastructure that is relatively low risk, low cost and has low structural requirements compared to, for example roads or bridges, and therefore offers a logical test bed for new materials and designs. With thermal comfort, safety and efficiency for users in mind, environmentally responsible designs would also minimize impacts across the life cycle including material embedded energy and cost and maintain natural ecosystems and processes. ANMs and alternative designs hold significant promise in these arenas; however, have not gained widespread adoption within the built environment as a means of reducing UHI.

2.1.2 Keyword Search

To assess the technological readiness level of ANM and GSI technologies for application in the reduction of transportation induced urban climate warming, literature was collected using relevant keyword searches in the Web of Science, Scopus, Transportation Research Information Services, and Google Scholar databases. Keyword combinations used in this study are summarized in Table 1 and include all possible combinations of a first and second term. The first term provided several options to capture relevant urban climate literature while the second term provided several options for ANM or GSI technologies respectively. ANM terms included “high performance concrete,” developed for bridge or buildings applications where weight and durability, chemical resistance and flexural performance tradeoffs are a priority. These materials have high performance standards relative to Portland cement concrete (PCC) and can incorporate novel material aggregates and require less material volume to achieve design specifications. While potentially higher cost, their increased performance characteristics and potential for reduced thermal mass would make them a novel material in the context of urban heat reduction technologies. Additional terms were included to capture pavements with novel hydrodynamic properties including "pervious pavement" and "pervious concrete" which each have continuous pore structures that allow the passage of water through the material potentially restoring or partially restoring evapotranspiration processes. Finally, a set of terms to capture the inclusion of air entrained materials with the potential for lower thermal mass and insulating properties were also included. In addition to GSI, specific GSI technologies including "retention pond" and "planter box" were included in the search as their incorporation into sidewalk and road corridor design has the potential to reintroduce source and process pathways for the restoration of evapotranspiration processes.

The timeframe for collected literature was focused on the last 10 years to best capture advances in alternative pavement technologies. A total of 9731 papers were retrieved from the combined databases.

Table 1. Systematic Literature Review Keyword Combinations

Term 1	Conjunction	Term 2
"UHI" OR "Urban Heat" OR "Extreme Heat" OR "Urban Cool Island" OR "Urban Cooling Island" OR "Urban Climate"	AND	"high performance concrete" OR "pervious pavement" OR "aerated concrete" OR "air entrained concrete" OR "alternative concrete design" OR "autoclaved concrete" OR "pervious concrete" OR "green stormwater infrastructure" OR "stormwater retention pond" OR "constructed wetland" OR "bioswale" OR "riparian buffer" OR "planter box" OR "tree box"

2.1.3 Inclusion Criteria

A series of inclusion criteria were established to ensure the final body of literature was both relevant and robust. First, duplicate papers were removed leaving N = 5,431. Editorials and non-peer reviewed literature were further excluded, as were incomplete or inaccessible records and those not published in English leaving N = 1,947. All remaining papers including review papers and peer-reviewed literature were assessed for study relevance and separated for further analysis under two categories: advanced and novel material (ANM) pavements and green stormwater infrastructure (GSI). Literature reviews were further segregated for summary analysis. Because of the large number of review papers published between 2020 and 2021, peer-reviewed literature retained for further analysis was published between 2019 and 2023. A standard PRISMA diagram is included as Figure 2 summarizing the literature collection, selection and exclusion criteria process. A total of 90 review papers (43 GSI; 47 pavement), 215 peer reviewed ANM pavement papers, and 256 GSI papers were further reviewed. A subset of 88 papers (24 GSI and 64 Pavement) directly addressed the urban heat magnitude or mitigation related to the focal technology.

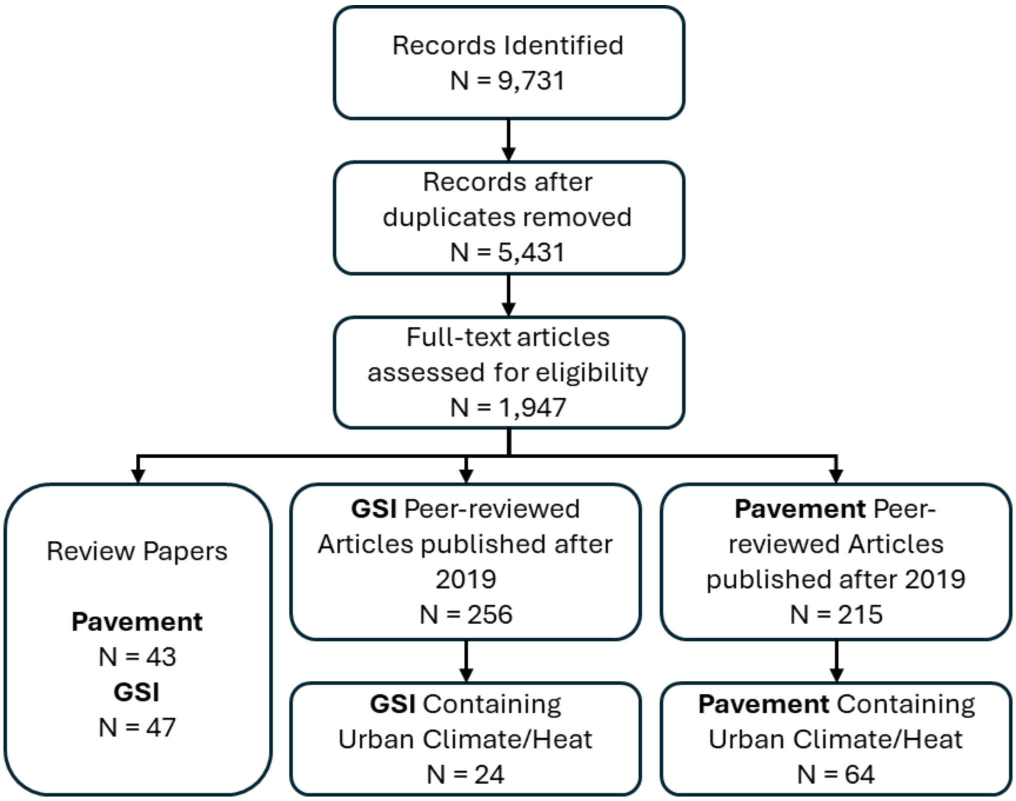

Figure 2. PRISMA Summary of Study Inclusion Process

2.2 Literature Review Summary

2.2.1 Summary of Literature Reviews

Significant recent work has been conducted to review the state of the GSI and ANM literatures. A total of ninety (N = 90) review papers were collected, with roughly half covering topics related to GSI (N = 43), the other half covering topics related to pavement science (N = 47). The vast majority of these were published within the last five years (91%).

A topical analysis is summarized in Figure 3. While the majority of pavement review papers evaluated heat, durability and the freeze-thaw cycle in some capacity, green stormwater research topics were more focused on water related themes including stormwater runoff, water quality and flooding with more minor coverage of heat and thermal comfort considerations. This is likely due to historical research and funding priorities for GSI as a stormwater management technology, with efforts to quantify heat reduction conducted as a co-benefit and not the central objective of implementation.

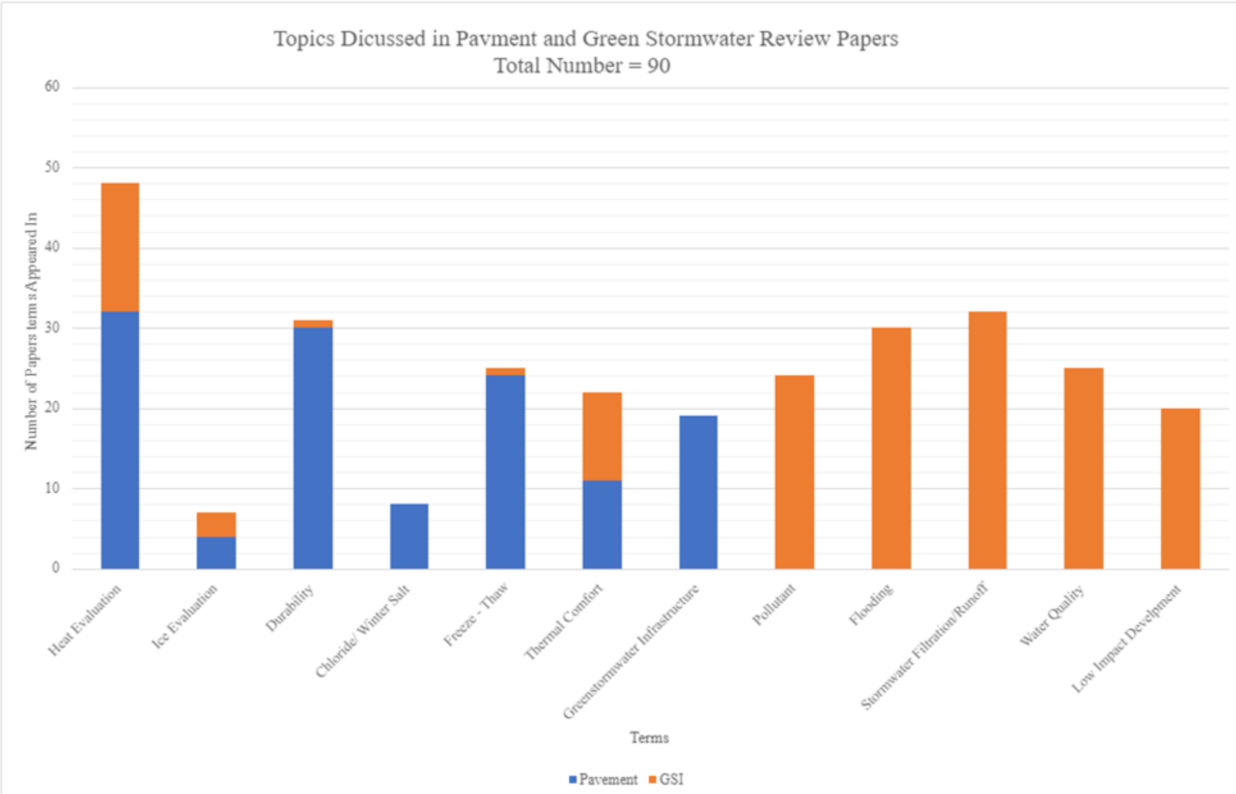

Figure 3. Topical summary of review papers for advanced and novel pavements (blue) and green stormwater infrastructure (orange)

Comprehensive reviews of the state of pavement technology are included (*45*), as was a review of the thermal processes and physical tradeoffs between those thermal properties in designing pavement solutions to optimize the thermal properties of asphalt pavements for cooling or heating under different conditions, for example, summer heat and winter snow melt respectively (*51*). Several studies review the utility and properties of phase change materials in achieving cool pavement objectives (*52*). One review focused on the gap that exists between research, industry and building codes and rating systems which may be limiting the efficacy and efficiency of efforts to mitigate UHI (*36*).

While GSI is recognized as a viable strategy for mitigating urban heat and improving thermal comfort, few of the GSI review papers directly addressed the question of heat and UHI mitigation specifically with the vast majority of the attention going toward stormwater, water quality, flooding and similar concerns. One systematic review evaluated 165 studies and found that most lacked methodological consistency and were conducted at micro scales, thus missing the effect of larger connected systems on the holistic impact of greening in urban environments (*53*). Additional gaps included geographical contexts including the global south, and methodological consistency across studies (*53*). A second review study similarly found a heavy reliance on the ENVI-met modeling software tool and similar micro-scale focus of the reviewed studies (*54*), while another study found a lack of research on threshold-size-based studies limiting policy relevant findings (*11*).

2.2.2 Advanced and Novel Pavement Materials Literature, 2019-2023

A total of 215 peer reviewed manuscripts, published between 2019 and 2023, were systematically reviewed across nine thematic areas that span the topics of interest in this study (see Figure 4) including performance during warm and cold seasons, general durability, stormwater performance and environmental impact. Papers were often found to address multiple thematic areas.

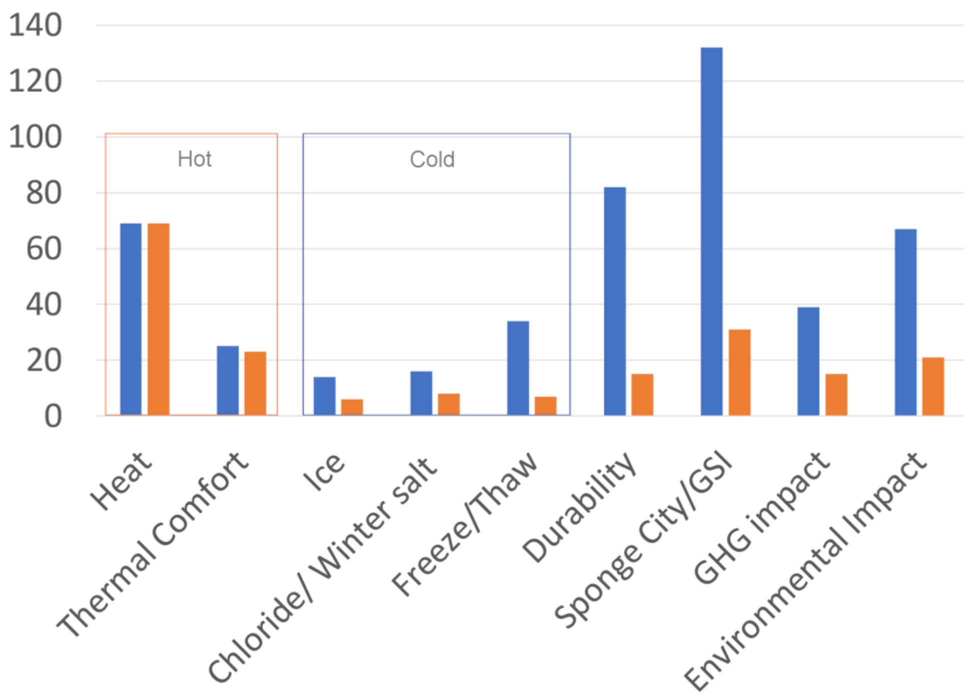

Figure 4. Topic summary ANM peer-reviewed literature 2019-2023 including hot and cold season topics, durability, stormwater performance and environmental impacts. Blue bars indicate the full literature collection, orange bars indicate topics covered by the subset of papers that also addressed heat.

Two of the thematic areas were related to warm season performance including material or air temperature (32%, N = 69) and human thermal comfort (12%, N = 25). An additional three thematic areas were focused on cold season performance including ice (7%, N = 14), chloride or winter salt (7%, N =16), and freeze/thaw performance (16%, N = 34). General durability (38%, N = 82) was the second most addressed thematic category. While stormwater performance (61%, N = 132) was by far the most frequent thematic topic. Environmental impacts including greenhouse gas footprint (18%, N = 39) and general environmental impacts (31%, N = 67) were also addressed within the corpus. The subset of papers that addressed heat was also assessed for topical overlap with the other thematic areas. Of note, just 15 papers (7%) addressed both cold and warm season topics.

The majority of papers in this corpus reported experimental results (81%, N = 174) from either in situ, or laboratory analysis. Laboratory analysis was conducted primarily to measure and quantify material properties including, for example, porosity, fatigue loading, stress-strain relationships, and strength in compression and bending. A subset of the papers, 45 papers (21%) had model building components using either statistical or finite element methods to translate experimental findings to more general contexts.

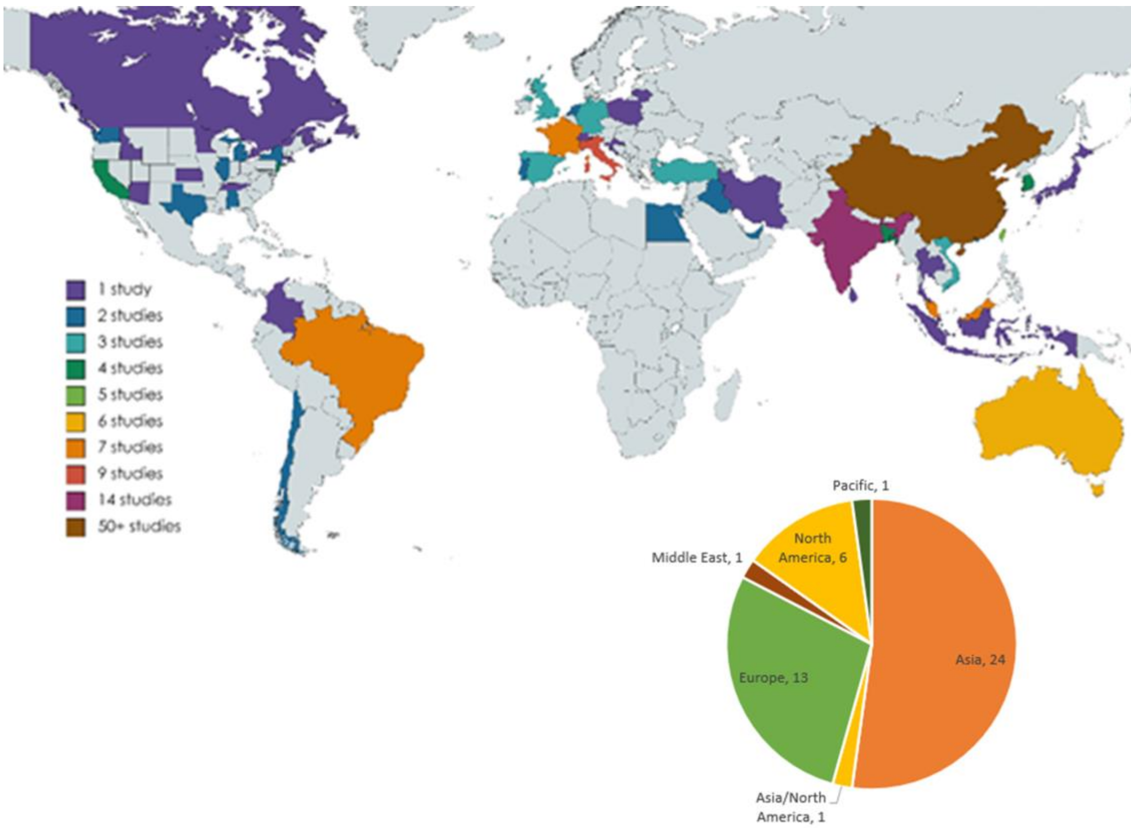

Figure 5. Geographic distribution of pavement papers including (inset pie chart) the region for pavement papers specifically addressing heat.

The reviewed papers reported results from studies conducted in a globally diverse geography as summarized in Figure 5. Most of the research conducted relating to the scope of this project have been done in China, with Tongji University in Shanghai producing eight works in the past 5 years. The African continent had the least amount of research, with only two studies conducted in Egypt. The studies were mostly conducted in areas near a largely populated city that experiences a hot season. It is important to note that the countries that experience a very cold winter and a mild summer like Sweden, Russia, and Iceland were not represented in the collected literature; the only exception is one study conducted in Canada.

Pervious concrete or asphalt was the most reported on ANM (73%, N = 158) with authors using the terms previous, permeable and porous variably and interchangeably. Additional papers discussed novel and recycled aggregates, including glass, fibers, coal ash, along with pigmented and reflective pavements.

2.2.2.1 ANMs to Reduce Urban Heat

The papers that addressed urban heating comprised just 32% (N = 215) of the reviewed studies with previous pavements again well represented in the subset at just over half of studies (52%, N = 69). Just a third of the heat related studies addressed thermal comfort metrics while roughly 10% addressed cold season topics including ice, chloride or winter salt and freeze/thaw durability. General durability was addressed by 22% (N = 69) of the studies as was the greenhouse gas impact of either the material or its in situ implementation.

The research team assessed this body of literature for an additional set of themes related to the thermodynamic processes controlling the development of the urban heat island anomaly including thermodynamic material properties that control the absorption, storage and release of heat from the material and the effect of those processes on the thermal environment (see Figure 6).

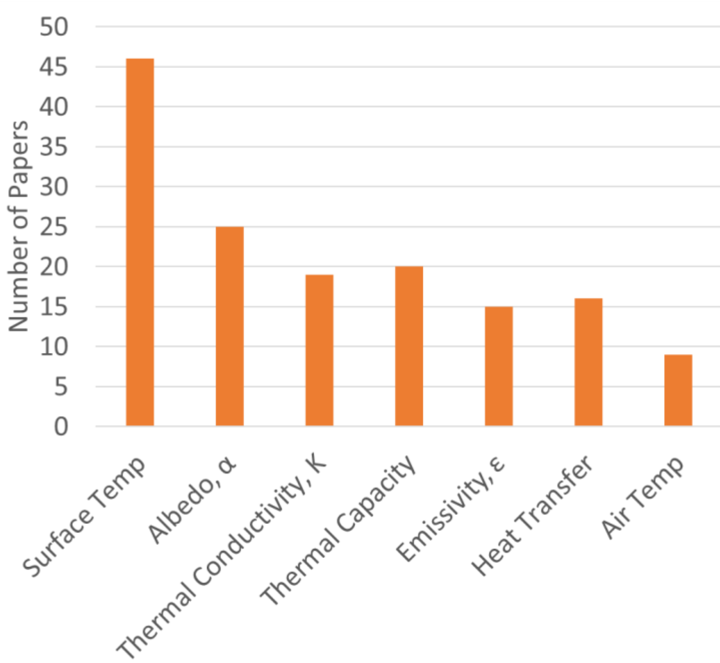

Figure 6. Thermal property theme summary for peer reviewed pavement papers that also addressed heat.

The majority of studies (67%, N = 69) were focused on the surface temperature of the material under investigation. As discussed in the introduction, lower surface temperatures generally result in lower air temperatures as they are a reflection of lower thermal capacity and can be more easily measured using remote observation platforms compared to air temperature. Just 13% (N = 69) of the heat related studies addressed air temperature and all but one of those also addressed surface temperature as an indicator of material performance.

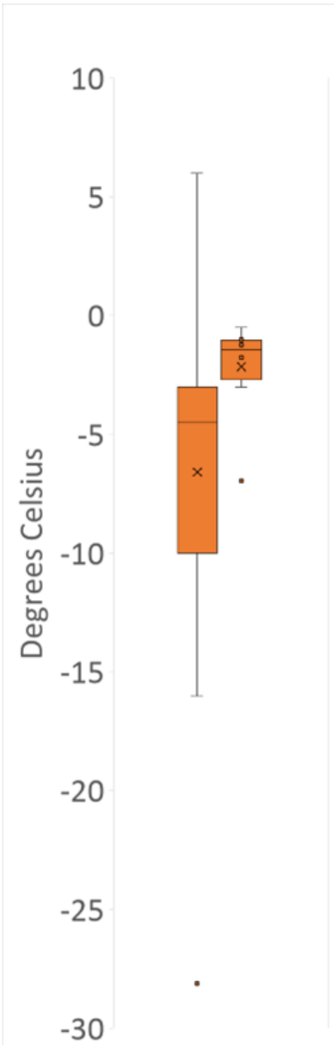

Figure 7. Temperature reduction potential of advanced and novel pavement technologies

The team conducted a meta-analysis of the reported temperature reductions reported by this subset of the studies and the results are summarized in Figure 7. The mean surface temperature reduction reported in the reviewed studies was -6.6 degrees Celsius (-11.8 degrees Fahrenheit). The range of reported values however spanned 34 degrees Celsius including increases in temperatures as large as 6 degrees Celsius (10.8 degrees Fahrenheit). Importantly, these positive values indicating an increase in thermal storage in the built environment relative to traditional PCC applications was found to occur when permeable pavements were implemented under dry conditions (*55*). The availability of moisture is critical for the effective functioning of these materials, providing a means of transporting large amounts of energy out of the system via evapotranspiration processes. Additional studies examined scenarios of wetting and design specifications with different material thickness, providing nuanced understanding of design alternatives, and confirming this result.

The median reduction in air temperature was smaller and had less variation. For the reviewed literature, the mean temperature reduction found from applications of novel pavement materials was -2.1 degrees Celsius (3.8 degrees Fahrenheit).

Several studies investigated the efficacy of novel aggregate materials including quartzite aggregates (*56*) and glass microspheres (*57*, *58*). The quartzite aggregate was investigated at a 50%, 75% and 100% replacement rate and found to reduce surface temperatures by 3.75 degrees Celsius at the highest level of replacement (*56*). The high thermal diffusivity was identified as the driving factor in its efficacy however the study also reports thermal conductivity and heat capacity measured during a 2-hr laboratory experiment (*56*).

The glass microspheres were evaluated across both thermal and road performance metrics and found to be less effective at reducing surface temperatures relative to the quartzite aggregate material. The glass microspheres were effective in reducing the surface temperature between 1 and 2 degrees Celsius or 23% as relative to the control standard (*58*). The same study assessed both the thermal capacity and the heat transfer of the novel material reported from laboratory experiment (*58*). The other study reported the thermal conductivity as well as surface temperature (*57*).

The additional studies included in the meta-review were assessed across a wide range of methodological parameters including the control material, experimental duration, heating method, instruments, modeling software used, etc. Significant variability was found across parameters making it difficult to fully contextualize the reported finding without further analysis.

2.2.3 GSI Literature 2019-2023

Of the corpus of peer reviewed studies addressing GSI that were identified as part of the literature search (N = 256), less than ten percent, or a total of 24 studies addressed issues of urban heat. Of that, seven studies (29%) reported experimental results, more than half (54%) reported the results of modeling or simulation that did not collected in situ observations, and an additional three studies (12.5%) proposed multi-criteria decision-making frameworks that included urban heat mitigation as a criteria objective.

The subset of studies reporting experimental findings were geographically diverse, reporting results from labs around the world and on every continent except Africa. Two of the studies reported results from vertical greening systems (*59*, *60*). One investigated the effect of irrigation flow rate on temperature reduction finding a local air temperature reduction of 3.4 degrees Celsius under the highest flow rate conditions (*59*). The second study investigated species composition which they found to have a variable impact on air temperature reduction (*60*). Three additional experimental studies investigated the temperature reduction potential of in situ combinations of green infrastructure (*61–63*). The investigation of complex interactions and synergistic effects on temperature variability and atmospheric dynamics was primarily conducted using virtual modeling environments (*64–70*). While two studies investigated The effect of temperature on the water quality performance of constructed wetlands

Several studies reported the development of frameworks or tools to guide the selection and implementation of GSI projects (*71–74*). One of those studies was specifically focused on the application of GSI in the context of arid climates where the availability of water can complicate the efficacy of implementation (*73*). Additional studies report modeling tools designed to facilitate participatory engagement in the design and implementation of projects within a broader urban context allowing designers the ability to evaluate alternative designs across multiple criteria including cost, water quality and urban heating (*74*).

2.3 Literature Review Analysis and Discussion

2.3.1 Technology Readiness Assessment

Based on the reviewed literature, an initial assessment of the technology readiness for both advanced and novel pavement materials (ANM) and green stormwater infrastructure GSI) as means of reducing urban heat island impacts was made (*75*). For both ANM and GSI technologies, the complex design environment means that a traditional readiness level assessment is only possible if provided within the context of specific scenario states. For instance, permeable pavements, both a GSI and ANM technology, have been modeled and demonstrated in situ suggesting a high level of technology readiness. However specific caveats, including the availability of water mean the operating conditions required for effective performance outcomes (reducing urban temperatures) are narrow and specific with operations outside of those conditions possibly resulting in negative or counterproductive outcomes. While some material components such as novel aggregates show promising results in laboratory experiments, suggesting a TRL3-4, additional materials such as permeable pavements are likely at TRL7-8. For materials and designs that are at higher levels of technology readiness, further evaluation across both efficacy and durability and maintenance categories would be required to characterize the materials as fully ready (TRL9) and while evident, this information was also the most limited within the reviewed literature. Widespread implementation and systematic monitoring and validation assessments across climatological and urban design contexts is required.

The nuance evident in the multiple technologies and design requirements for effective implementation results in a more complex design space where multiple technologies must be considered and evaluated against a single traditional material or design choice (PCC or asphalt). Evaluation of these tradeoffs becomes context specific and may benefit from decision-making tools that help guide the evaluation of tradeoffs and system optimization across multi-criteria environmental objectives. There was evidence of such tools and frameworks within the reviewed corpus, with regional or climatological variability in evidence as well. However, the limitations and adoption of such tools was outside the scope of this study and not evaluated. Regardless, adoption is likely to be limited to contexts where there is a high level of planning and design capacity.

2.3.2 Gaps and Limitations

Several gaps were identified in the reviewed literature. For instance, there was a lack of attention paid to ice and snow conditions and the effect of chloride salts used in deicing operations on novel pavement and porous pavements in particular. Additional geographic exclusions were also noted with strong representation in Asian and European regions with less coverage in the global south and the south Asian pacific and South America. Additionally, none of the papers reviewed addressed de-paving scenarios or the value tradeoff of pavement design standards.

It was further noted that experimental test section research in context and fully instrumented is rare and was not observed within the literature. This may make it difficult for practitioners to be convinced that the novel solutions are a viable option for their community.

CHAPTER 3. SURVEY OF AGENCIES

To assess the state of professional practice in the adoption of advanced and novel pavement materials and green infrastructure designs for the purpose of mitigating urban heat from transportation infrastructure, a survey of practitioners was conducted. The results are reported here.

3.1 Survey Data Collection Methodology

The purpose of this survey was to better understand the existing knowledge, open questions and potential barriers that exist for transportation professionals in the implementation of novel pavement materials and designs specifically in sidewalk applications. The target populations for distribution included transportation practitioners serving in municipal government roles which included planners, engineers, and public works decision-makers. The project's target sample size was 20-30 qualitative responses. Examining the answers would allow the research team to gain a better understanding of existing professional practice, particularly outside of large metro areas. The survey asked a total of 20 questions, many of which had two to four follow-up questions. The survey itself was broken into four general topic areas:

- General Information Questions gathered insights into town city/size, typical number of sidewalk projects per year, respondent tenure in position, and respondent educational background.
- General Knowledge and Experience Questions gauged the respondents' general knowledge of alternative sidewalk materials and designs, including high performance concretes, permeable pavements, and green stormwater infrastructure approaches.
- Concern and Awareness of Extreme Heat Questions included the respondent's perceived capacity to address the challenge through professional activities.
- Asset Management and Barriers to Implementation questions focused on identifying whether alternative materials and designs were being implemented or considered.

The survey took approximately 15-20 minutes to complete on the Qualtrics survey platform. The study originally started out with a telephone interview design. However, low interview response rates necessitated a change to an online survey approach. The following sections discuss the evolution of the data collection methodologies over the course of the project.

3.1.1 Initial Data Collection Methodology and Reconfiguration

The original data collection protocol for this study was designed as a series of qualitative, semi-structured interviews with transportation practitioners serving in municipal government roles including planners, engineers, and public works decision-makers. The protocol instrument was collaboratively developed by project team members at both the University of Vermont and Georgia Tech with the intent that each institution would recruit and conduct interviews in their region, the northeast and southeast respectively. Both institutions received IRB approvals for the recruiting protocol, materials and survey instrument. One of the strengths of this method is the ability of the interviewer to gather detailed information from respondents (*76*) and allow for unanticipated responses and appropriate question follow-up. Respondents are also afforded more leeway to answer questions in their own words, which allows for flexibility on behalf of the researcher and the respondent as it provides more insight than pre-prepared answers in a survey (*76*). However, data collection of this type can introduce interviewer bias and non-standardized responses that require additional analysis time to transcribe and code which can be time consuming and cost prohibitive (*76*).

With a target of 10-15 interviews at each institution, researchers at both UVM and Georgia Tech encountered challenges recruiting and scheduling a sufficient number of willing interviewees. It often takes several exchanges with a potential interviewee to schedule a time for an interview, irrespective of the medium used to contact them. The data collection team soon realized the most significant challenge was getting potential interviewees in the sample to respond. For the Georgia Tech team, an estimated 75% of calls went straight to voicemail, the majority of which gave no answer, whether positive or negative, even after researchers contacted them to follow up. In a similar vein, most emails sent went unanswered even after multiple follow-ups. Moreover, approximately half of the total respondents deferred the researchers to another department or individual who could better answer their questions. In some cases, referred individuals were in a position with a higher level of authority within the organization, in other cases, they were in another department (e.g., planning or public works). Of the 154 individuals contacted, seven agreed to an interview, meaning that the sample had a total response rate of 4%. The means for which data was recorded was left to the discretion of the respondent: 1.) using the in-app recording feature for Zoom or Teams interviews, 2.) using the recording feature on the data collection team member's phone for phone interviews, 3.) detailed notes taken by data collection team members if an in-person interviewee was uncomfortable being recorded, and 4.) the written responses submitted by respondents via email. However, despite the wide array of choices, researchers noted that many participants were reluctant to have their responses recorded in any capacity, though written responses (either taken down by a researcher or submitted by an interviewee) seemed to be regarded with less suspicion than a recorded telephone conversation or Zoom meeting.

The Vermont team meanwhile was able to conduct and transcribe three interviews out of an original outreach pool of 38, a total response rate of 7.9%. The region in which the team was working then experienced a major flood disaster that severely impacted the transportation network and required emergency response across the state by individuals who had been identified as potential recruits. The emergency persisted for the duration of the recruiting period, and at that time, the team temporarily suspended recruiting.

In consideration of the experience of both teams, and to reduce the burden on respondents to schedule a specific time to meet with the research team, the decision was made to pivot to an online survey. The interview protocol was then modified for implementation in the online survey platform Qualtrics. The revised survey instrument, and data management protocols, was again approved with exemption by institutional review boards at both participating institutions.

3.1.2 Surveys as a Means of Data Collection

The purpose of this section is to provide a general understanding of the data collection vehicle that researchers eventually selected. Online questionnaires, otherwise known as surveys, are considered to be cost-effective data collection method that enable researchers to collect a high volume of responses in a relatively short time frame (*77*). Surveys can also gather data on topics that are sensitive or not readily observable or from specific segments of a population (*77*, *78*). They further do not require direct interaction with the research team and may therefore provide a greater sense of anonymity regardless of data protection protocols. Surveys are also described as "unobtrusive" as respondents can complete them at their own convenience and on their own schedules (*78*). Online surveys also allow respondents to take as much time as necessary to answer questions and enables them to complete questionnaires in multiple sessions, thereby enhancing their convenience (*78*). It was chiefly these characteristics that drove the decision to reconfigure the interview-style questionnaires into online surveys.

Although some sources indicate that electronic surveys have lower response rates compared to telephone and postal surveys (*79*), studies show that the average response rate of online surveys is still approximately 44.1% of participants (*80*).

Surveys also provide unique opportunities to provide anonymity to respondents that goes beyond di-identification in post-collection analysis. The survey instrument designed for this project, for instance, only recorded the respondent's job title/rank and the county, organization, or municipality they represented, which provided a screen of anonymity for individuals who might be reluctant to otherwise respond.

3.1.3 Sample Identification and Recruiting Methods

An understanding of the sample identification and selection methods of this report provides valuable context to the analyses used to examine the data produced during this phase of the project. The pool of potential respondents for this survey included a total of 836 individuals. These respondents were identified through the process of navigating government sites for towns, counties, and state level departments. The departments that were primarily focused on were engineering public works and city planning. When taking note of respondents' important contact information was gathered including names of contacts, job title, town, email (if available), and phone number (if available). The data collection team identified a total of 216 stakeholders in the state of Georgia, 483 in Florida, 71 in Vermont, 44 in New Hampshire, and 22 in the state of Maine with contact information posted online as potential interviewees. Snowball sampling from outreach to this initial pool of potential respondents resulted in the addition of 73 new or updated contacts of which 50 new contacts were from Florida, 19 from Georgia, 2 from Maine, and 2 from Vermont.

As in the prior phase, members of the data collection team reached out to these potential respondents via phone to inform them that they were going to send their organization a survey asking about their knowledge, policies, and processes involving the use of ANMs and GSI in sidewalks to mitigate the urban heat island effect. When reaching out to potential respondents the data collection team referred to different scripts depending on the type of contact being made with the respondent. It was found that shorter scripts with information focused on confirming contact information for respondents was most effective. After contact information was confirmed or obtained, the next step in the process was to contact the respondent through a scripted email containing information as to what the survey would be about as well as information as who to contact for more information about the survey.

3.1.4 Survey Design

The survey was divided into seven sections, totaling 50 questions. Each section is described below:

3.1.4.1 Section 1: Welcome Page

Section 1 served as a cover page and consent agreement for the survey. It contained information regarding the background and purpose of the project, the length and anticipated duration of the survey, and a contact phone number where any questions could be directed. The Welcome Page also identified respondent legal rights pertaining to the survey.

3.1.4.2 Section 2: Baseline Information

Section 2 had four questions and collected basic demographic information from each respondent which would help contextualize later responses. The survey asked respondents to identify their state, county, city, or local government, and other organization for which they work. Further, the survey asked respondents to list their job title and years of experience in that role. Finally, the survey asked respondents to state the number of sidewalk projects they and/or their department/unit are typically involved with each year.

3.1.4.3 Section 3: General Experience with ANM and GSI Implementation

Section 3 included two questions each with seven sub questions to gauge the respondent's level of knowledge regarding material alternatives for Portland Cement Concrete (PCC). The survey asked respondents to list any materials they were aware of being used in sidewalk and roadway construction other than Portland cement concrete and asphalt. The survey then asked respondents if their unit/organization has used any of those materials in the past, and if so, what factors motivated the decision to use an alternative material and if the organization had a satisfactory experience working with that material. Likewise, the survey asked respondents similar questions regarding awareness of unconventional sidewalk or roadway design and/or construction techniques.

Table 2. Survey Section and Question Summary

Section	Title	Number of Questions
1	Welcome Page	0
2	Baseline Information	4
3	General Experience with ANM and GSI Implementation	14
4	Extreme Heat Exposure and Mitigation	5
5	Asset Management and Project Selection	20
6	Thermal Comfort	5
7	General Information	2
	TOTAL	50

3.1.4.4 Section 4: Extreme Heat Exposure and Mitigation

Section 4 included five questions to assess the institutional awareness of and response to the UHI effect. The survey asked respondents if their organization considered heat mitigation as a goal or objective in their transportation planning process and if heat has ever influenced transportation project design or material selection within their organization. Respondents were also asked if they receive concerns or complaints regarding heat from the public, and were asked to rate their organization’s level of concern about pedestrian heat exposure and the UHI effect. Finally, the survey asked respondents to list the way(s) in which their organization mitigates the impacts of the UHI effect.

3.1.4.5 Section 5: Asset Management and Project Selection

Section 5 asked twenty questions related to the asset management procedures within their organization. Respondents are asked to state the approximate total length of sidewalks maintained by the organization (in miles). Larger communities that have more sidewalks may also have higher degrees of variability in the UHI across their community. Further, respondents are asked to describe the process used to prioritize the implementation of various projects, and if heat mitigation is a factor in the project prioritization process. Moreover, respondents are asked to describe the level of information contained within their organization’s sidewalk inventory (I.e., is it complete, incomplete, or nonexistent, does the inventory contain the locations of ramps, curb cuts, crossings, and other pedestrian assets, does the inventory contain information regarding the quality of the sidewalks and pedestrian assets, is there any other information contained within the inventory, etc.). Respondents are also asked if their organization performs regular inspections of sidewalks and other pedestrian assets and, if so, how often those inspections take place, and if this work is performed by agency staff or contracted to an external organization. Finally, respondents are asked to disclose the funding mechanisms for pedestrian infrastructure projects (i.e., are they publicly funded, funded by the adjacent property owners, etc.).

3.1.4.6 Section 6: Thermal Comfort

Section 6 asked four questions to further investigate issues related to pedestrian thermal comfort. Respondents are asked to assess the severity of thermal discomfort for vulnerable populations within their jurisdiction, as well as to list specific projects and policies implemented by their organization to help improve thermal comfort.

3.1.4.7 Section 7: General Information

Finaly, Section 7 asked two final questions to allow respondents to list any UHI mitigation strategies put into practice by their organizations that may not have been mentioned in the survey, and to provide respondents the opportunity to list any other information they think might be relevant to the study.

3.1.5 Bottlenecks and Setbacks

As mentioned in previous sections, the research and data collection team experienced a number of setbacks during the data collection phase. This report section discusses these issues, how they impacted the data collection phase, and what the team did to overcome them or improve data collection. Not surprisingly, these issues mostly related to the weaknesses associated with qualitative interviews as a data collection method. However, the circumstances associated with this project had some unique facets that warranted further exploration.

The first issue, which was outlined in previous sections, was that the initial data collection methodology (semi-structured interviews) proved to be too burdensome for respondents. To address the issue, the team determined that an online survey would be more effective. However, it took time for the researchers to complete survey development tasks, which produced delays in other areas of the project. Restructuring the interview questions into an online survey took a day of staff labor. This stage involved reviewing best practices in survey design, researching the Qualtrics platform, reviewing norms and conventions of previous surveys produced by the team, and converting the initial interview questions into a survey format. An additional day of staff time was spent producing new project materials for research assistants, including updated scripts, processes, and tracking materials as well as several README documents for new team members.

A second issue that presented itself during the data collection process had to do with sample selection optimization. Due to the initial low response rates prior to the survey reconfiguration, the team elected to widen the scope of work to include additional states including Florida, Massachusetts, and New Hampshire. Casting a wider net meant that response rates would likely improve, which enabled the team to meet the target sample size. However, this also caused some delays as it meant that the research and data collection team had to spend additional time and resources to repeat the sample selection process in these areas.

One issue that was encountered while obtaining a list of contacts was the issue surrounding the government websites the contacts were found through. Many of the websites were out of date, and it was therefore difficult to find correct contact information for individuals currently employed in target positions as well as accurate phone numbers and email addresses. In some cases, municipal websites did not include contact information for public works or engineering departments.

Organization was a primary factor in many setbacks the data collection team had when recording responses to survey inquiries. Each data collector was assigned a workload consisting of 10-40 contacts where they needed to reach out to ask for their participation in the survey. Logging these interactions between data collectors and potential participants proved to be a daunting task. Each collector tracked the response they received, when it was received, and other additional notes. This information was then updated into a master spreadsheet where new contacts, notes, and additional materials were stored in a central location. The management of this spreadsheet system required constant upkeep.

Due to the novelty of the research question, setbacks were be expected to some degree. Future research attempting to repeat or expand upon this process should account for the issues identified in this section during the design phase. By planning for these issues in advance, their impact in later stages of the project will likely to be reduced. Despite these setbacks, the results produced by the analysis phase of the project still provided significant insights into how agencies are thinking about pedestrian heat mitigation; however, these results may not be widely generalizable and require further investigation.

3.2 Survey Response Summary

This section examines the responses to the survey. A total of 836 stakeholders were contacted regarding this project, including 216 in Georgia, 483 in Florida, 71 in Vermont, 44 in New Hampshire, and 22 in Maine. Of these, 96 indicated a willingness to participate in the study and 30 completed the survey.

3.2.1 Response Rate Statistics

Understanding the sample identification and selection methods of this report gives valuable context to the analyses used to examine the data produced during this phase of the project. During the initial interview phase of the project, the data collection team identified a total of 216 stakeholders in the state of Georgia, 483 in Florida, 71 in Vermont, 44 in New Hampshire, and 22 in the state of Maine with contact information posted online as potential interviewees. The pool of potential respondents for this survey was a total of 836. Of these, 96 stakeholders indicated willingness to participate in the study, including 25 from Georgia, 55 from Florida, 9 from Vermont, 3 from New Hampshire, and 4 from

Maine. The survey was distributed to the 96 willing participants, and 30 survey responses were received, including 13 from Georgia, 9 from Florida, 6 from Vermont, 1 from New Hampshire, and 1 from Maine. These response rates are summarized in Table 3. The largest response rates were in the states where the participating institutions are located and may in part have been influenced by participants familiarity with or the reputation of the research institutions. Future researchers might consider strategic partnerships with local transportation research centers to leverage trust and existing relationships in recruiting survey respondents.

Table 3. Survey Response Rates by State

State	Total Contacts	Willing Participants (% of total contacts)	Responses Received (% of total contacts)
Georgia	216	25 (11.6%)	13 (6.0%)
Florida	483	55 (11.4%)	9 (1.9%)
Vermont	71	9 (12.7%)	6 (8.5%)
New Hampshire	44	3 (6.8%)	1 (2.3%)
Maine	22	4 (18.1%)	1 (4.5%)
Total	836	96 (11.5%)	30 (3.6%)

The survey asked respondents to state their current job title. Of the 29 responses received, 18 indicated that they perform an engineering role (e.g., civil engineer, county engineer, director of public works, etc.), 8 indicated that they perform a planning role (e.g., transportation planner, director of planning, etc.), and 3 indicated that they perform a political or administrative role (e.g., special advisor for infrastructure projects, town clerk). Respondents were also asked to state the number of years in which they have worked for their current organization. Responses ranged from 2 years to 37 years, with a median of 10 years. Figure 8 shows the distribution of respondent-reported job tenure (years of experience).

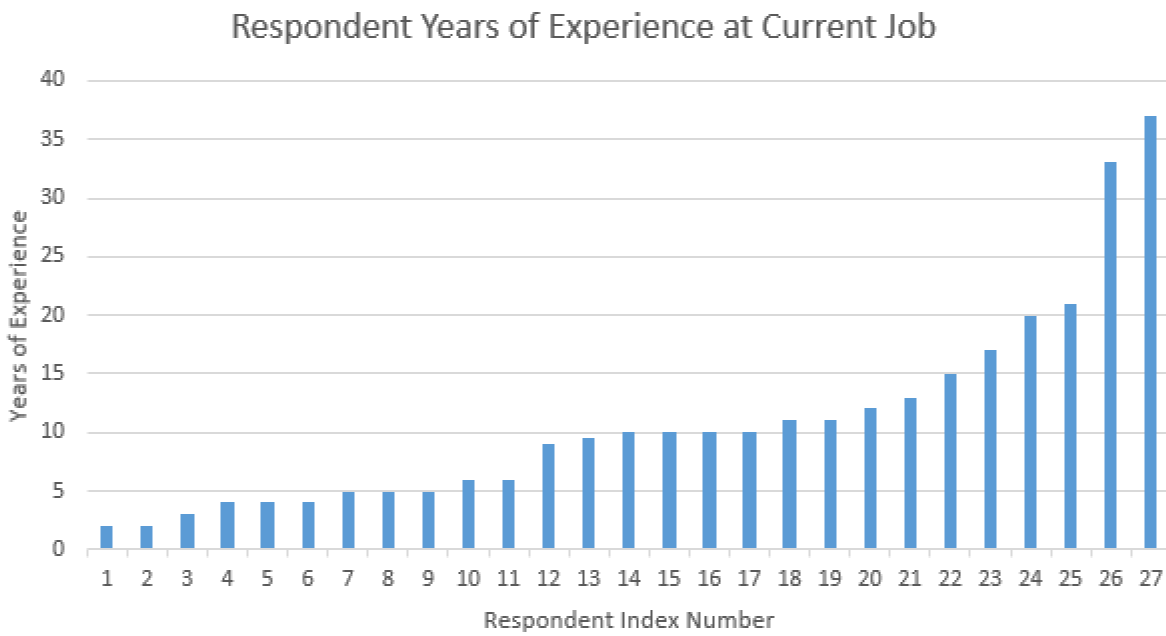

Figure 8. Respondent Years of Experience at Current Job

3.2.2 General Experience Responses

The following section reports the survey respondent's awareness of alternative materials and design techniques for sidewalk construction projects, as well as their experiences with using alternative materials and design techniques.

3.2.2.1 Alternative Materials for Sidewalk Construction

The survey asked respondents to list the alternative materials to Portland cement concrete or asphalt for sidewalk construction projects that they were aware of at the time of taking the survey. As shown in Table 4, nine respondents reported that they were not aware of any alternate materials or not sure if they were aware of any alternate materials. The remaining 21 respondents listed several materials, including permeable pavements (16 responses), gravel (five responses), and rubber (five responses), among other materials.

Table 4. Awareness of Alternative Pavement Materials

Question 2a: Do you know about any alternatives to Portland Cement Concrete and asphalt materials used in sidewalk construction or other transportation infrastructure? For example, alternatives might include high performance concretes or permeable pavements.	Number of Responses
Yes	21 (70%)
No	5 (16.7%)
Not Sure	4 (13.3%)

Table 5. Number of Alternate Materials Listed per Response

Question 2b: Please list these materials below: (Number of Alternate Materials Named)	**Number of Responses**
0	9
1	6
2	7
3	3
4	2
5	3
Median	1.5

Table 6. Alternate Materials Named by Number of Responses

Alternate Material Name	**Number of Responses**
Permeable / Porous Pavements	16
Gravel / Loose Asphalt	8
Pavers	7
Rubber	4
Bricks	3
High Performance Concrete	2
Cobblestone	2
Geogrids	1
Deconstructed Granite	1
Raised Wooden Platforms	1
Unpaved Dirt Roads	1
Green Walkways / Grass Pavers	1
Recycled Materials	1

Respondents who listed alternative materials were then asked if their organization has ever specified the use of one of those materials. As shown in Table 7, nine respondents (42. % of those who were aware of alternate materials) indicated that their organization had used at least one of the alternate materials, including glass aggregate, gravel, permeable / porous pavements, rubber, and turf blocks. Respondents were also asked to explain what may have motivated their organization to use an alternative material (see Table 8).

Table 7. Organizations Specifying the use of Alternative Pavement Materials

Question 2c: Has your organization specified the use of any of these materials?	**Number of Responses**
Yes	9
No	11
Not Sure	1

Table 8. Motivations for Using Alternate Pavement Materials

Question 2e: What may have motivated the organization's decision to specify or use the alternative sidewalk materials? Please check all that apply:	Number of Responses
To reduce ambient temperatures or the impact of heat micro-environments and heat-related hazards	1
To increase surface permeability and reduce runoff and flooding	6
For economic reasons (cost of materials, less expensive maintenance and upkeep costs, etc.)	2
To meet compliance requirements for federal grants or other sources of funding	1
For other environmental reasons not listed above	3
For other non-environmental reasons	1
Not sure	0
Prefer not to answer	0

Only one respondent indicated ambient temperature reduction as a motivator for adopting an alternative paving material (7%, N = 14), while the most frequent motivation was to increase surface permeability and reduce runoff or flooding (43%, N = 14). Other reasons for using alternative materials identified by the respondents included the presence of tree roots in the construction location that necessitated the use of an alternate material, the use of rubber to improve comfort for runners and joggers, and to comply with the National Historic Preservation Act.

Respondents were asked to rate their organization's experience with using these alternate materials as highly satisfactory, satisfactory, neither satisfactory or unsatisfactory, unsatisfactory, or highly unsatisfactory. Of these options, 50% of question respondents rated their experience as highly satisfactory (10%, N = 10) or satisfactory (40%, N = 10). In contrast, 20% of question respondents indicated having an unsatisfactory experience while the balance indicated having a neither satisfactory nor unsatisfactory experience (20%, N = 10) or not sure (10%, N = 10). The survey also provided respondents with an option to explain their response. One respondent indicated having a neither satisfactory nor unsatisfactory experience using permeable pavement, citing the increased ongoing maintenance required to keep voids clear. Two respondents indicated a satisfactory experience using rubberized walking surfaces, but cited drainage issues and decreased durability in comparison to more traditional materials. One respondent indicated an unsatisfactory experience using turf, citing difficulty for wheelchair users to traverse the surface.

Table 9. Organizational Satisfaction with using Alternative Pavement Materials

Question 2f: In general, what has been the organization's experience with these materials?	Number of Responses
Highly Satisfactory	1
Satisfactory	4
Neither Satisfactory nor Unsatisfactory	2
Unsatisfactory	2
Highly Unsatisfactory	0
Not Sure	1

3.2.2.2 Alternative Design and Construction Techniques for Sidewalk Construction

The survey asked respondents to list the alternative design and/or construction techniques for sidewalk construction projects that they were aware of at the time of taking the survey. Seventeen respondents (58%, N = 29) reported that they were not aware of any alternate design or construction techniques or not sure if they were aware of any alternate materials. The remaining twelve respondents (41%, N = 29) listed several design techniques, including bioswales (four responses), general GSI (two responses), and tree boxes / planters (two responses), among other materials and GSI technologies.

Table 10. Awareness of Alternative Construction Techniques

Question 3a: Do you know of any alternatives to traditional 4-inch poured Portland Cement Concrete in sidewalk designs and construction techniques? For example, alternatives might include incorporating green stormwater infrastructure, or printed voids in the design of sidewalks.	Number of Responses
Yes	12
No	9
Not Sure	8

Table 11. Number of Alternative Design or Construction Techniques Named by Number of Responses

Question 3b: Please list those design or construction techniques below: (Number of Alternate Techniques Named)	Number of Responses
0	20
1	5
2	3
3+	2
Median	0

Table 12. Alternate Design or Construction Techniques Named by Number of Responses

Alternate Design or Construction Technique Name	Number of Responses
Bioswales	4
General GSI	2
Tree Boxes / Planters	2
Printed Voids	1
Silva Cells	1
Stamped Pavement	1
Colored Pavement	1
Pea Gravel Concrete	1
Brick / Cobblestone	1
Rain Gardens	1
Intentionally Sloped Roads (for stormwater purposes)	1
Retention Ponds	1
Permeable Pavement	1

Respondents who were able to list alternative design or construction techniques were also asked if their organization has ever specified the use of one of those materials. Seven respondents (58.3% of those who were aware of alternate design or construction techniques) indicated that their organization had used at least one of the alternate design or construction techniques, including bricked sidewalks, bioswales, rain gardens, detention ponds, and other various forms of GSI technology. Further, respondents were asked to explain what may have motivated their organization to use an alternative design or construction technique. Those results are displayed in Table 14. The most highly cited reason for using alternative design or construction techniques identified by the respondents was increase surface permeability and reduce stormwater runoff (36%, N = 11). The second most commonly cited reason was to reduce ambient temperatures or the impact of heat micro-environments and heat-related hazards (18%, N = 11). Additional responses cited improved aesthetics, equity and economic considerations.

Table 13. Organizations Specifying the use of Alternative Design or Construction Techniques

Question 3c: Has your organization specified the use of any of these design or construction techniques?	Number of Responses
Yes	7
No	5
Not Sure	0

Table 14. Motivations for Using Alternate Sidewalk Design or Construction Techniques

Question 3e: What may have motivated the organization's decision to specify or use the alternative sidewalk designs or construction techniques?	Number of Responses
To reduce ambient temperatures or the impact of heat micro-environments and heat-related hazards	2
To increase surface permeability and reduce runoff and flooding	4
For economic reasons (cost of materials, less expensive maintenance and upkeep costs, etc.)	1
To meet compliance requirements for federal grants or other sources of funding	0
For other environmental reasons not listed above	3
For other non-environmental reasons	1
Not sure	0

Respondents were asked to rate their organization's experience with using these alternate design or construction techniques as highly satisfactory, satisfactory, neither satisfactory or unsatisfactory, unsatisfactory, or highly unsatisfactory. Of these options, one respondent was unsure how satisfactory the organization was with the experience, and the rest of the respondents of this question indicated having a satisfactory experience (86%, N = 7).

Table 15. Organizational Satisfaction with using Alternative Pavement Materials

Question 3f: In general, what has been the organization's experience with these design or construction techniques?	Number of Responses
Highly Satisfactory	0
Satisfactory	6
Neither Satisfactory nor Unsatisfactory	0
Unsatisfactory	0
Highly Unsatisfactory	0
Not Sure	1

3.2.3 Transportation Planning and Extreme Heat Exposure and Mitigation

When asked, just three respondents (10%, N = 28) indicated that their organization identifies heat mitigation as a goal or objective in the transportation planning process, while 20 respondents (71%, N = 28) indicated that heat mitigation was not an explicit goal or objective of their organization during the transportation planning process. An additional five respondents (18%, N = 28) were unsure.

Though not an explicit goal, eight respondents (29%, N = 28) indicated that heat related concerns have influenced their organization's design or material selection choices on a transportation project at least once, while 14 respondents (50%, N = 28) indicated that heat related concerns have, to their knowledge, never influenced design choices or material selections, with six respondents (21%, N = 28) reporting that they were unsure.

Table 16. Heat Mitigation as a Transportation Planning Goal

Question 4a: Does your organization identify heat mitigation as a goal or objective in the transportation planning process?	Number of Responses
Yes	3 (10.7%)
No	20 (71.4%)
Not Sure	5 (17.9%)

Table 17. Heat as an Influencing Factor in Transportation Planning and Engineering

Question 4b: Has the concern for heat ever influenced the design or materials used in projects that you have worked on or know about?	Number of Responses
Yes	8 (28.6%)
No	14 (50.0%)
Not Sure	6 (21.4%)

Respondents were also asked to rate their organization's level of concern about pedestrian heat exposure, extreme heat, and urban heat islands. More than half of the respondents (52%, N = 27) describe their organization as being either extremely or somewhat concerned about pedestrian heat exposure, extreme heat, and urban heat islands in the community. The balance were either neutral, somewhat or unconcerned. Specifically, two respondents (7%, N = 27) to this question indicated an extreme level of concern from their organization, twelve respondents (44%, N = 27) indicated that their organization was somewhat concerned, seven respondents (26%, N = 27) indicated that their organization was neither concerned nor unconcerned, four respondents (15%, N = 27) indicated that their organization was somewhat unconcerned, and two respondents (7%, N = 27) indicated that their organization was entirely unconcerned.

Ten respondents (34%, N = 29) indicated that their organization receives heat related complaints or concerns from the public, while more than half, or 15 respondents (52%, N = 29), indicated that their organization does not receive heat related complaints or concerns. Four additional respondents (24%, N = 28) reported that their position does not interface with the public enough and they were therefore unsure about the prevalence of heat related complaints directed toward their organization.

Table 18. Public Concerns and Complaints Regarding Heat

Question 5: Does your organization hear about heat concerns or receive heat complaints from the public?	Number of Responses
Yes	10 (34.5%)
No	15 (51.7%)
Not Sure / My position does not interface with the public enough to determine this	4 (13.8%)

Table 19. Organizational Level of Concern Regarding Heat

Question 6: Describe your organization's level of concern about pedestrian heat exposure, extreme heat, and urban heat islands in the community in which you work.	Number of Responses
Extremely Concerned	2 (7.4%)
Somewhat Concerned	12 (44.4%)
Neither Concerned nor Unconcerned	7 (25.9%)
Somewhat Unconcerned	4 (14.8%)
Completely Unconcerned	2 (7.4%)

The survey gave respondents the opportunity to explain the ways in which their organization mitigates heat related concerns. Increasing tree canopy coverage was the most common strategy for mitigating heat related concerns. For instance, one director of public works noted that their city has a tree planting program. An engineering director reported that local parking lot design standards require a tree island every 12 spaces. In addition, one planning director reported that they are primarily involved with grant writing and project administration, and use their role to incentivize and promote heat mitigation techniques.

3.2.4 Asset Management and Project Selection

To assess the scale of influence, the survey asked respondents to approximate the number of miles of sidewalk maintained by their organization. Responses ranged from less than two miles to 200 miles. Roughly a third of respondents (32%, N = 28) reported that their organization does not maintain any sidewalks. Figure 9 shows the distribution of sidewalk miles maintained by each respondent's organization.

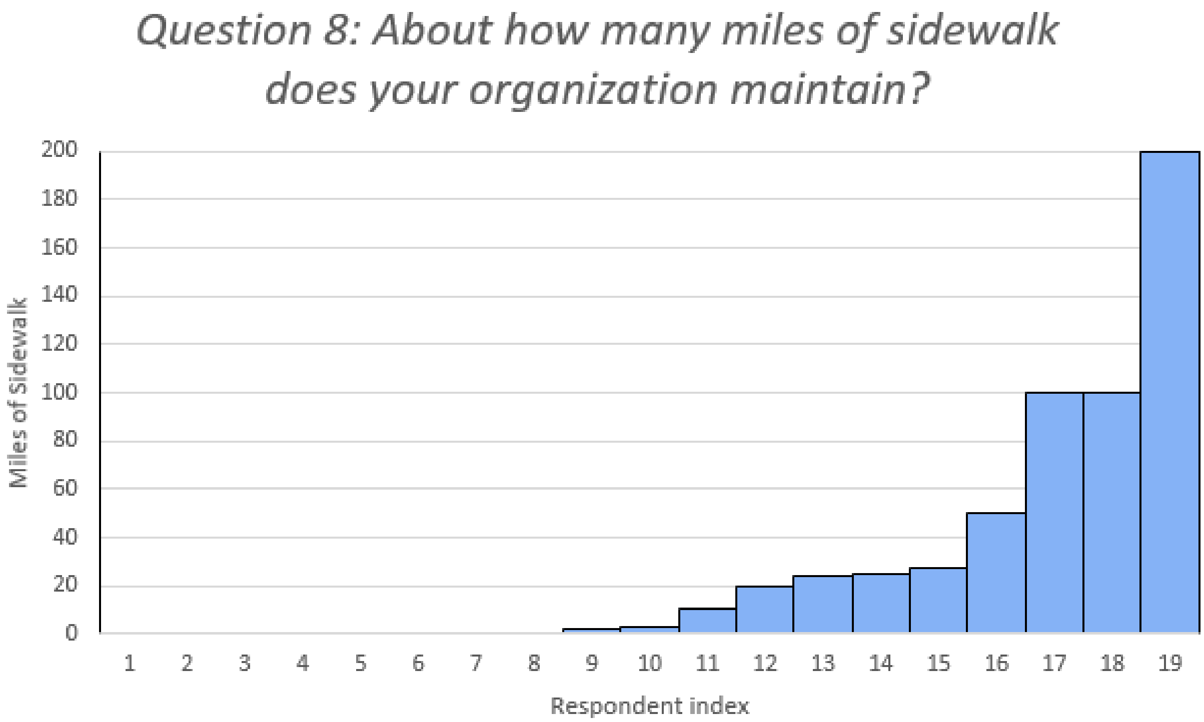

Figure 9. Responses to Question 8: About how many miles of sidewalk does your organization maintain?

Respondents were also asked to describe the process in which projects are prioritized for implementation by their regional planning agency. Fifteen respondents (54%, N = 28) indicated that their regional planning agency does have a project prioritization process, while ten respondents (36%, N = 29) indicated that there is no official project prioritization process in place, with an additional three respondents (11%, N = 28) reporting that they were unsure. Of those that indicated that there was a project prioritization process in place, ten reported (66%, N = 15) that there is a scoring rubric in place to evaluate projects for prioritization purposes, with four respondents (27%, N = 15) indicating that projects are prioritized using some other method.

Table 20. Pedestrian Project Prioritization Processes

Question 9a: Is there an official process used by the local or regional planning agency to prioritize the implementation of pedestrian infrastructure projects?	Number of Responses
Yes	15 (53.6%)
No	10 (35.7%)
Not Sure	3 (10.7%)

Table 21. Weighted Scoring Rubric Approach in the Project Prioritization Methods

Question 9b: In this project prioritization process, is there a scoring approach with weighting values that is employed?	Number of Responses
Yes	10 (66.7%)
No	4 (26.7%)
Not Sure	1 (6.7%)

Respondents were given the opportunity to describe the factors that influence project prioritization, and were also asked directly if heat mitigation was included in the project prioritization process. Only one respondent (3%, N = 29) indicated that heat mitigation was included in the prioritization process. The vast majority of respondents (83%, N = 29) indicated that heat mitigation was not a factor in the project prioritization process. An additional four responses (14%, N = 29) indicated they were unsure. Other reported factors considered in project prioritization decisions include project cost, aesthetics, pedestrian traffic volumes, proximity to trip origin points, proximity to schools, potential to connect disconnected portions of the sidewalk network, regulations, ADA requests, and classification of the adjacent roadway. One planner reported that public input is also considered in the project prioritization process, which provides a potential avenue for heat related concerns to influence the prioritization process.

Table 22. Heat Mitigation as a Factor in Project Prioritization

Question 9c: Is heat mitigation included in project prioritization decisions?	Number of Responses
Yes	1 (3.4%)
No	24 (82.8%)
Not Sure	4 (13.8%)

Roughly a third, or eight respondents (29%, N = 28) reported that their community has an asset management system to track pedestrian infrastructure. More than half, 15 respondents indicated (54%, N = 29) that they did not have an asset management system, while an additional 5 respondents (28%, N = 29) were unsure. In contrast, 16 respondents (59%, N = 29) indicated that their community maintains an inventory of sidewalks, while nine respondents (33%, N = 29) indicated a lack of a sidewalk inventory, and two respondents (7%, N = 29) were unsure. Of the responses indicating that a sidewalk inventory was maintained by their community, ten respondents (62%, N = 16) indicated that the sidewalk inventory is complete and current, whereas three respondents (19%, N = 16) indicated that the sidewalk inventory is complete but not current, and an additional three respondents (19%, N = 29) indicating that the sidewalk inventory for the community in which the work is incomplete. Eight survey respondents (29%, N = 29) indicated that their community has a community sidewalk inventory and tracks pedestrian asset condition, while 16 respondents (57%, N = 29) indicated that their community does not track asset condition, and four respondents (14%, N = 29) indicated that they were not sure. Respondents indicated that the types of information contained in their local sidewalk inventories include length, location, and condition.

Table 23. Prevalence and Completeness of Pedestrian Infrastructure Asset Management Systems

Question 11a: Does the community you work in have an asset management system for pedestrian infrastructure?	**Number of Responses**
Yes	8 (28.6%)
No	15 (53.6%)
Not Sure	5 (17.9%)
Question 11b: Does the community you work in have an inventory of sidewalks?	**Number of Responses**
Yes	16 (59.3%)
No	9 (33.3%)
Not Sure	2 (7.4%)
Question 11c: Is the inventory of sidewalks and other pedestrian assets complete or partial?	**Number of Responses**
Complete and Current	10 (62.5%)
Complete but not Current	3 (18.8%)
Partial	3 (18.8%)
Question 11d: Does the community you work in have an inventory of ramps, curb cuts, crosswalks, or other pedestrian assets?	**Number of Responses**
Yes	8 (28.6%)
No	13 (46.4%)
Not Sure	7 (25.0%)
Question 11e: Is the inventory of other pedestrian assets complete or partial?	**Number of Responses**
Complete and Current	3 (37.5%)
Complete but not Current	3 (37.5%)
Partial	1 (12.5%)
Not Sure	1 (12.5%)
Question 11f: Is pedestrian asset condition tracked in the local agency inventory?	**Number of Responses**
Yes	8 (28.6%)
No	16 (57.1%)
Not Sure	4 (14.3%)

Information was collected about two mechanisms for pedestrian infrastructure inspections including public reporting and agency inspections. With respect to sidewalk inspections by the public, 25 respondents (89%, N = 28) reported that there is a mechanism for members of the public to report infrastructure problems, compared to two respondents (7%, N = 28) indicating that no such mechanism exists and one additional respondent who was unsure. Regularly scheduled inspections, by contrast, are conducted by just under half (44%, N = 27) of respondents with ten responses (37%, N = 27) indicating a lack of regular sidewalk inspections and five unsure (19%, N = 27). When asked how often regular sidewalk inspections take place, respondents reported a range of responses, spanning from monthly on the most frequent end to once every two years on the least frequent end (see Figure 10).

Table 24. Prevalence of Mechanisms for the Public to Report Pedestrian Infrastructure Problems

Question 11h: Is there a mechanism for the public to report pedestrian infrastructure problems?	Number of Responses
Yes	25 (89.3%)
No	2 (7.1%)
Not Sure	1 (3.6%)

Table 25. Prevalence of Regularly Scheduled Pedestrian Asset Inspections

Question 11i: Do regular inspections of sidewalks or other pedestrian assets take place?	Number of Responses
Yes	12 (44.4%)
No	10 (37.0%)
Not Sure	5 (18.5%)

The survey also asked respondents to report the degree to which contractors are used to perform asset management work (as opposed to local agency staff) as a percentage of total labor. Five respondents (22%, N = 23) reported no use of contractors, five respondents (22%, N = 23) indicated 100% use of contracted labor, and 13 respondents (57%, N = 23) indicated a mix of agency and contractor labor. The average percent of contractor labor reported was 36.1%. Further, respondents were asked to report the specific tasks that are performed by contractors. These reported tasks include grants and funding applications, design, construction, large-scale planning, and maintenance.

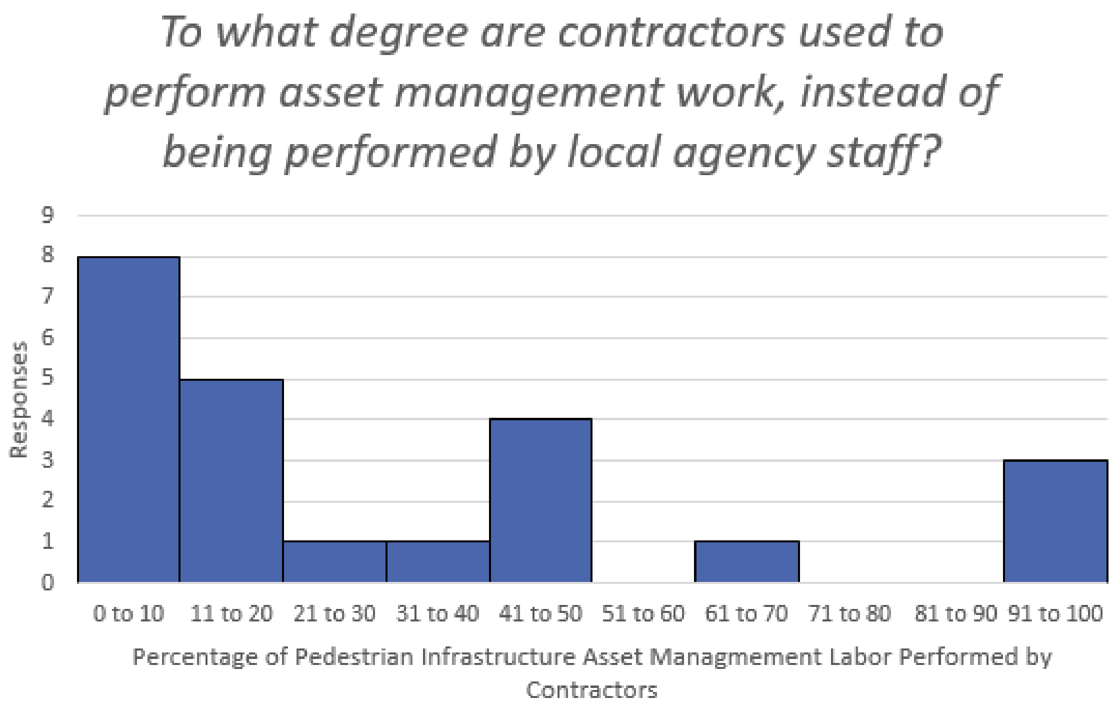

Figure 10. Distribution of Responses for Question 12a: To what degree are contractors used to perform asset management work, instead of being performed by local agency staff?

When asked, respondents listed a number of different mechanisms used to fund pedestrian projects with no dominant mechanism. These included municipal and county funding, state and federal grants, economic development funding, special purpose local option sales taxes (SPLOSTs), foundations, and through private developers.

3.2.5 Thermal Comfort

When asked about the existence of pedestrian thermal comfort issues under extreme heat within their jurisdictions, just four respondents (14%, N = 28) indicated that they were aware of issues, compared to 18 responses (64%, N = 28) suggesting that the respondent was not aware of any pedestrian thermal comfort issues in their community. Six respondents (21%, N =28) were unsure. Respondents were then asked to rate the severity of thermal discomfort for vulnerable pedestrian groups (e.g., the elderly, wheelchair users, chronic disease patients, etc.) on a scale of 1 to 5 with 1 being not at all severe discomfort, and 5 being extremely severe discomfort for vulnerable populations. The median score, with 10 responses (48%, N = 21) was 3, or moderately severe. On average, all respondents rated vulnerable population discomfort severity as 2.6/5. This was slightly higher (2.8/5) for respondents who reported being from the southeast (Georgia or Florida) and lower (1.8/5) for respondents who reported working in communities across New England (Vermont, New Hampshire or Maine). Just one respondent rated vulnerable population pedestrian discomfort as being extremely severe.

Table 26. Awareness of Local Pedestrian Thermal Comfort Issues

Question 14: Are you aware of any issues surrounding pedestrian thermal comfort under extreme urban heat within your jurisdiction?	Number of Responses
Yes	4 (14.3%)
No	18 (64.3%)
Not Sure	6 (21.4%)

Table 27. Severity of Thermal Discomfort for Vulnerable Pedestrian Groups

Question 15: On a scale of 1 to 5, how would you rate the severity of thermal discomfort for vulnerable pedestrian groups (e.g., elderly, wheelchair users, chronic disease patients) in your area?	Number of Responses
5 (Extremely Severe)	1
4	1
3 (Moderately Severe)	10
2	6
1 (Not at all Severe)	3
Average (All Responses)	2.6
Average (Georgia and Florida Only)	2.8
Average (Vermont, New Hampshire, and Maine Only)	1.8

Respondents were asked to describe the actions taken or policies implemented by their organizations to improve thermal comfort for pedestrians during extreme heat events. The majority of respondents indicated that they either were unsure (38%, N = 21) or did not take any actions or have policies implemented (43%, N = 21) to improve thermal comfort for pedestrians in their communities. Of those who did disclose specific actions or policies (24%, N = 21), examples included the installation of pocket parks and covered park bench areas, facilitating connections between various local organizations that can provide resources and/or advocate on behalf of policies that mitigate the impacts of extreme heat. Similarly, respondents were asked to list specific projects or initiatives in their area that are aimed at specifically protecting vulnerable pedestrian populations from the effects of urban heat, including those undertaken by organizations other than the respondent's own organization. Just two respondents (7%, N = 27) indicated that these projects or initiatives are present in their community, while the balance either reported an absence of these policies or initiatives (63%, N = 27) or were unsure (30%, N = 27). In an open-ended response, respondents listed specific examples of vulnerable population heat mitigation strategies which included the installation of cooling stations for the homeless and elderly, the construction of additional shaded walkways, and the planting of trees.

Table 28. Prevalence of Projects or Initiatives to Protect Vulnerable Groups from Urban Heat

Question 17a: Are there specific projects or initiatives in your area that are aimed at protecting vulnerable pedestrian groups from the effects of urban heat?	Number of Responses
Yes	2 (7.4%)
No	17 (63.0%)
Not Sure	8 (29.6%)

3.2.6 General Information

Respondents were asked to list any strategies or approaches being taken by their organizations to mitigate heat related hazards (e.g., GSI or other means) that were not mentioned in earlier survey questions. Responses included the prioritization of green stormwater projects, incentivizing and participating in education and networking related to green infrastructure.

Likewise, respondents were offered an opportunity to list anything they felt was important to consider with respect to sidewalk design, materials, or maintenance that had not already been covered by the survey. Some responses mentioned specific design features, such as shading, building canopies, planting urban forests, and deploying water misters. Other responses referred generally to cost and maintenance schedules. One response noted that concrete is more expensive and durable in comparison to asphalt, but asphalt is "softer" for users.

3.3 Survey Analysis and Discussion

This section evaluates the survey results as well as existing literature to identify the potential barriers that may prevent alternative paving materials including ANMs and green stormwater infrastructure from being used as tools to mitigate the urban heat island effect. This section also discusses the insights gained from survey respondents' past experiences with alternative paving materials and green stormwater infrastructure.

3.3.1 Awareness of and Experiences with Alternative Paving Materials and Green Stormwater Infrastructure

When considering the potential factors involved in decisions to use (or not use) alternative paving materials or green stormwater infrastructure, it is first necessary to evaluate the existing level of awareness among engineers, planners, and other relevant practitioners. This section evaluates current awareness of alternative paving materials and green stormwater infrastructure. This section also discusses the experiences survey respondents' have had with using alternative paving materials and green stormwater infrastructure.

3.3.1.1 Alternative Pavement Materials

The survey asked respondents the following questions to evaluate their awareness of and experience with alternative paving materials:

> *Question 2a. Do you know about any alternatives to Portland Cement Concrete and asphalt materials used in sidewalk construction or other transportation infrastructure? For example, alternatives might include high performance concretes or permeable pavements.*
>
> *Question 2b. Please list these materials below:*
>
> *Question 2c. Has your organization specified the use of any of these materials?*
>
> *Question 2d. Please list these materials below:*
>
> *Question 2e. What may have motivated the organization's decision to specify or use the alternative sidewalk materials?*
>
> *Question 2f. In general, what has been the organization's experience with these materials?*

Out of 27 responses received for question 2a, 19 respondents indicated that they were aware of alternatives to Portland cement concrete and asphalt materials, while eight respondents selected "no" or "not sure". The average tenure of employment at their current organization among respondents answering "yes" to question 2a is 11.1 years, compared to 10.4 years for those who answered "no" or "not sure". Four out of 7 respondents in the northeast (Vermont, New Hampshire, or Maine) responded "yes" to question 2a, while 15 out of 20 respondents in the southeast (Georgia or Florida) responded "yes". As such, this data does not reveal an obvious relationship between a respondent's geographic location and their awareness of alternative paving materials, nor does it reveal a relationship between a respondent's tenure of employment and their awareness of alternative paving materials.

Sixteen engineers responded to question 2a, of which 12 responded "yes". Likewise, 8 planners responded to question 2a, of which 6 responded "yes". The three remaining responses were from non-planning / non-engineering administrative roles in municipal governments. From this group, one respondent answered "yes". There does not appear to be a substantial difference in alternative paving material awareness between engineers and planers, though engineers and planners may have a greater awareness of alternative paving materials in comparison to other fields (a larger sample size of non-planners/non-engineers would be necessary to investigate this further).

Question 2b asked respondents to list the types of alternative paving materials they were aware of. Seventeen out of 19 respondents mentioned permeable / pervious pavements in their response. Other common responses included gravel / loose asphalt (8/19 responses), pavers (7/19 responses), and bricks / cobblestone (4/19 responses). Fourteen out of 19 respondents listed two or more types of alternative paving materials, and 8 out of

19 respondents listed three or more alternative paving materials. This suggests that those who are aware of alternative paving materials in general tend to be aware of several types of alternative paving materials.

Questions 2d, 2e, and 2f investigated respondent's experiences with using alternative pavement materials. Each of these materials are discussed in the following paragraphs:

Permeable Pavements / Surfaces:

Three respondents reported that they have used permeable pavements / surfaces in the past. All three of those respondents cited a desire to increase surface permeability and reduce runoff and flooding as a primary motivating factor for the use of permeable pavements. One of the three respondents also cited a desire to reduce ambient air temperatures or the impact of heat micro-environments and heat related hazards. These respondents were given the opportunity to share additional details:

> *Respondent 1 [satisfactory experience] – "We used rubber trail surface for a 5K trail in our largest park at 14' wide. It works well except the property is very flat and therefore it stays wet under the trail. This causes some sinking and damage to the surface. Thus requiring frequent repairs."*
>
> *Respondent 2 [neither satisfactory nor unsatisfactory experience] – "Annual on-going maintenance required to keep the voids unclogged to allow stormwater to flow through."*

Brick and Planter Islands

One respondent shared their experience working with brick and planter islands. They cited greenspace requirements and a desire for good aesthetics as primary motivations for their use. Likewise, they reported that their experience was "highly satisfactory".

> *Respondent 1 [highly satisfactory experience] - brick walkways with tree planters and flower planters creates a nice downtown.*

Turf Blocks

One respondent shared their experience working with turf blocks. They cited a desire to increase surface permeability and to reduce runoff and flooding as primary motivations for their use. However, they reported that their experience was "unsatisfactory".

> *Respondent 1 [unsatisfactory experience] – "The material is difficult to walk on, especially for elderly people and those with disabilities. The material shifts and settles and contractors are not familiar with the material in terms of construction methods and compaction. The material silts up and does not drain as well over time as initially intended."*

3.3.1.2 Green Stormwater Infrastructure

The survey asked respondents the following questions to evaluate their awareness of and experience with alternative sidewalk design and construction techniques, such as the incorporation of Green Stormwater Infrastructure:

> *Question 3a. Do you know of any alternatives to traditional 4-inch poured Portland Cement Concrete in sidewalk designs and construction techniques? For example, alternatives might include incorporating green stormwater infrastructure, or printed voids in the design*
>
> *Question 3b. Please list these design or construction techniques below:*
>
> *Question 3c. Has your organization specified the use of any of these design or construction techniques?*
>
> *Question 3d. Please list these design or construction techniques below:*
>
> *Question 3e. What may have motivated the organization's decision to specify or use the alternative sidewalk designs or construction techniques?*
>
> *Question 3f. In general, what has been the organization's experience with these designs or construction techniques?*
>
> *Question 19. Are there any strategies or approaches your organization is currently doing that involve green stormwater infrastructure or mitigating heat-related hazards that were not mentioned in this survey?*

In response to question 3a, 11 out of 26 respondents reported an awareness of alternative sidewalk and construction techniques, such as the incorporation of green infrastructure. In comparison, 8 respondents answered "no", and 7 respondents answered "not sure". Of respondents from the northeast (Vermont, New Hampshire, Maine), there were 2 "yes" responses, 2 "no" responses, and 3 "not sure" responses. Meanwhile, among respondents in the southeast (Georgia, Florida), there were 9 "yes" responses, 6 "no" responses, and 4 "not sure" responses. The sample size is too small to draw meaningful conclusions about regional variations in awareness, but the relatively higher "yes" rate in the southeast does suggest that regional differences may possibly exist.

Those who responded "yes" to question 3a were asked to list the alternative design or construction techniques that they were aware of. Green stormwater infrastructure, such as bioswales, planters, and rain gardens, were the most common response. Other responses mentioned permeable pavements, the use of bricks for decorative purposes, and colored concrete.

Those who responded yes to question 3a were then asked if their organization has ever specified the use of those alternative design or construction techniques. Of the 11 respondents who were aware of alternate techniques, 5 indicated that their organization has previously specified the use of one or more alternative design or construction techniques. One "yes" respondent noted that as a planning agency, their organization doesn't have specific design or construction standards, but their organization does advocate for the inclusion of green stormwater infrastructure in projects through funding incentives.

Respondents were offered the opportunity to share their experiences with various alternative sidewalk design or construction techniques. They are shared below, organized by technique:

Green Stormwater Infrastructure

Two respondents identified green stormwater infrastructure as an alternative sidewalk design or construction technique. They cited a desire to increase surface permeability and to reduce runoff and flooding as the primary motivation for its incorporation. Both respondents indicated that their experiences were "satisfactory."

Planters

One respondent identified the use of planters as an alternative sidewalk design or construction technique. They cited aesthetics as their organization's primary motivation for incorporating planters. They reported that their experience with using planters was "satisfactory".

Colored and Stamped Concrete

One respondent identified the use of colored and stamped concrete as an alternative sidewalk design or construction technique. They cited aesthetics as their organization's primary motivation for using colored and stamped concrete. They reported that their experience with using colored and stamped concrete was "satisfactory".

The survey asked respondents "Are there any strategies or approaches your organization is currently doing that involve green stormwater infrastructure or mitigating heat-related hazards that were not mentioned in this survey?" Several responses mentioned public policy. One engineer noted that they comply with Georgia's coastal stormwater supplement, which encourages green stormwater infrastructure. One Floridian planner noted that they are developing language to mandate stormwater mitigation in transportation projects. Another Floridian planner noted that all newly constructed buildings must be LEED certified in their jurisdiction. One municipal administrator in Vermont noted that they have funding available for voluntary (i.e., not required by permit) green stormwater projects, but have not received any applications for those funds.

3.3.2 Pedestrian Infrastructure Asset Management

Design and construction decisions are often influenced by the environment in which the project will be located. Solutions that may be ideal in some contexts may not be feasible in other contexts. Factors such as sidewalk network size, asset management structures, and funding structures could influence the built form of new projects. This section discusses the environments in which each respondent's sidewalk network exists in an attempt to identify contextual factors that may promote and/or dissuade the use of alternative materials or construction methods in pedestrian infrastructure.

3.3.2.1 Sidewalk Network Descriptions

The survey asked respondents the following questions to help contextualize the sidewalk networks within their jurisdiction:

> *Question 8: About how many miles of sidewalk does your organization maintain?*
>
> *Question 11a: Does the community you work in have an asset management system for pedestrian infrastructure?*
>
> *Question 12a: To what degree are contractors used to perform asset management work, instead of being performed by local agency staff?*
>
> *Question 12b: For what aspects of pedestrian asset management and planning activities are contractors used instead of being performed by local agency staff?*

Question 8 provides valuable insight into the scale of the sidewalk networks among the response pool. Of 25 responses, eight indicated that their organization is not responsible for maintaining any sidewalks. All eight of these respondents were in planning roles, as opposed to engineering or municipal administration. An additional six respondents were unsure. The remaining responses indicated sidewalk network lengths of less than 2 miles, 3 miles, 20 miles, 20 miles, 23 miles, 25 miles, 27 miles, 50 miles, 100 miles, 100 miles, and 200 miles, respectively. Eight out of 11 respondents who maintain any length of sidewalks were able to list at least one alternative sidewalk material and/or alternative sidewalk construction technique when asked to do so in questions 2b and 3b, respectively. In comparison, five out of eight respondents who did not maintain any sidewalks were able to name at least one alternative sidewalk material and/or construction technique. From this data, we do not have sufficient evidence to conclude that there is a correlation between organizational responsibility for maintaining sidewalk networks and organizational knowledge of alternative materials or techniques. Likewise, a larger sample size would be necessary to observe any correlation between sidewalk network length and organizational knowledge of alternative materials or construction techniques.

Question 11 allows us to gain insight into the asset management structures used by respondent organizations, thereby potentially allowing us to identify any asset management related factors impeding the adoption of alternative sidewalk material or construction techniques. The existence of a pedestrian infrastructure asset management system is a prerequisite for the broad implementation of strategies relating to the material or construction techniques of pedestrian infrastructure. However, only seven of 25 respondents indicated that their community maintains a pedestrian infrastructure asset management system, with 14 “no” responses and four “not sure” responses. Five of the seven (71%) affirmative responses were from respondents who also indicated that their organization has previously specified the use of alternative pedestrian infrastructure materials and/or design techniques, while only eight of the 18 (44%) non-affirmative responses were from organizations that had previously specified the use of alternative materials and/or construction techniques. It is possible that there is a correlation between the presence of a pedestrian infrastructure asset management system within a community and the use of alternative materials or design techniques within that community. Perhaps more precisely, a municipality that is robust enough to maintain a pedestrian infrastructure asset management system may be more likely to consider alternatives in comparison to a municipality that lacks the capacity, expertise, and/or desire to maintain a pedestrian infrastructure asset management system.

Question 12 asks respondents to report the degree to which external contractors are used to perform asset management tasks, on a scale of one to 100. A high rate of contractor labor would potentially indicate that local agency staff may be lacking in asset management expertise. Of 21 responses, four respondents indicated that external contractors are not used at all, three respondents indicated that external contractors perform 100% of the asset management work, and the remaining 14 responses reported a mix of external contract labor and internal agency labor. The median response was 20% contractor labor, and the average response was 34% contractor labor. Figure 10 shows the distribution of these responses.

The types of labor performed by contractors varied among respondents. Some reported a reliance on contractors for general maintenance tasks, such as snow shoveling. Other respondents indicated that their municipality maintains general infrastructure databases, but contracts out design and construction work. Likewise, several responses indicated that planning work was performed externally. One response specified that external agencies were used for grant applications, and another response reported that external contractors were used for ADA compliance inspections. The degree of external contractor engagement and types of labor precludes the ability to draw conclusions about the influence of these factors without additional data.

3.3.2.2 Planning and Decision Making

The survey asked respondents the following questions to help contextualize the decision-making processes in their jurisdiction pertaining to pedestrian infrastructure:

> *Question 9a: Is there an official process used by the local or regional planning agency to prioritize the implementation of pedestrian infrastructure projects?*
>
> *Question 9b: In this project prioritization process, is there a scoring approach with weighting values that is employed?*
>
> *Question 9c: Is heat mitigation included in project prioritization decisions?*
>
> *Question 9d: Can you describe the factors including regulatory, economic, safety, and other decision-making criteria that determine project prioritization, material selection, and design for a given sidewalk project?*
>
> *Question 13a: How are sidewalk projects funded? Is there a funding split between the town/city/county/state and the private property owners?*

Question 13b: How are other pedestrian infrastructure projects funded? Is there a split between the town/city/county/state and the private property owners?

Out of 26 respondents, only one indicated that heat mitigation is a factor in project prioritization decisions, with an additional four respondents unsure. When asked to describe the factors that determine project prioritization, material selection, and design for pedestrian infrastructure projects, eight respondents listed costs or finances as an influential factor. Six respondents mentioned considering the surrounding land use, such as proximity to schools, parks, and/or other substantial trip origin/destination points. Likewise, six respondents mentioned connectivity or functionality as a factor. Separately, two respondents noted that special consideration is given to connecting sidewalk networks that are currently disconnected from each other. Five respondents cited regulatory factors, such as the Americans with Disabilities Act or local zoning codes. Five respondents mentioned safety. Additional factors mentioned by the survey respondents include community input (N = 4), maintenance (N = 3), equity (N = 2), aesthetics (N = 1), drainage (N = 1), and the functional classification of the adjacent road (N = 1).

Out of 24 responses, 16 respondents reported that their pedestrian infrastructure projects are funded through a mix of federal, state, and local funding sources. Often, the project type would dictate the funding source. For instance, one respondent noted that new large sidewalk construction would likely be an 80/20 split between federal and local funding, smaller scale new construction would likely be a 50/50 split between state and local funding, and maintenance of existing sidewalks would likely be funded entirely through local funding sources. The majority of responses indicated that they are at least partially reliant on grant funding. Several responses also noted that private developers are required to contribute to infrastructure funding when constructing a new development.

3.3.3 Organizational Prioritization of Urban Heat Mitigation

Organizational commitment (or lack thereof) to mitigating urban heat is a factor that would likely influence the use of alternative materials or design techniques in pedestrian infrastructure. This section examines the extent to which heat mitigation is considered in the decision-making process.

3.3.3.1 Identification of Urban Heat as a Concern

The survey asked respondents the following questions to assess their prioritization of heat mitigation:

Question 4a: Does your organization identify heat mitigation as a goal or objective in the transportation planning process?

Question 4b: Has the concern for heat ever influenced the design or materials used in projects that you have worked on or know about?

Question 5: Does your organization hear about heat concerns or receive heat complaints from the public?

Question 6: Describe your organization's level of concern about pedestrian heat exposure, extreme heat, and urban heat islands in the community in which you work.

Question 14: Are you aware of any issues surrounding pedestrian thermal comfort under extreme urban heat within your jurisdiction?

Question 15: On a scale of 1 to 5, how would you rate the severity of thermal discomfort for vulnerable pedestrian groups (e.g., elderly, wheelchair users, chronic disease patients) in your area?

Only two out of 26 responses indicated that their organization identifies heat mitigation as a goal in the transportation planning process. One of the affirmative responses was from the northeast (Vermont, New Hampshire, Maine), and one was from the southeast (Georgia, Florida). On the other hand, eight out of 26 responses reported that heat has influenced design or material choices in the past, with all eight affirmative answers coming from the southeast region (approximately half of the southeast region response pool). This suggests that heat related factors may be an influencing factor even if heat mitigation is not explicitly listed as an organizational goal.

Nine of 26 respondents indicated that their organization receives complaints from the public about heat (29% of the northeast responses, 39% of the southeast responses). One respondent noted that their position does not interface with the public enough to answer this question.

Question six asked respondents to report their organizations level of concern about pedestrian heat exposure. On balance, respondents from the southeast region were more likely to report that their organization is somewhat or extremely concerned. "Somewhat concerned" was the most common response, but "extremely concerned" was one of the least selected options. This suggests that heat mitigation is likely relatively low on the list of priorities for many organizations. The full distribution of these responses is shown in Figure 11.

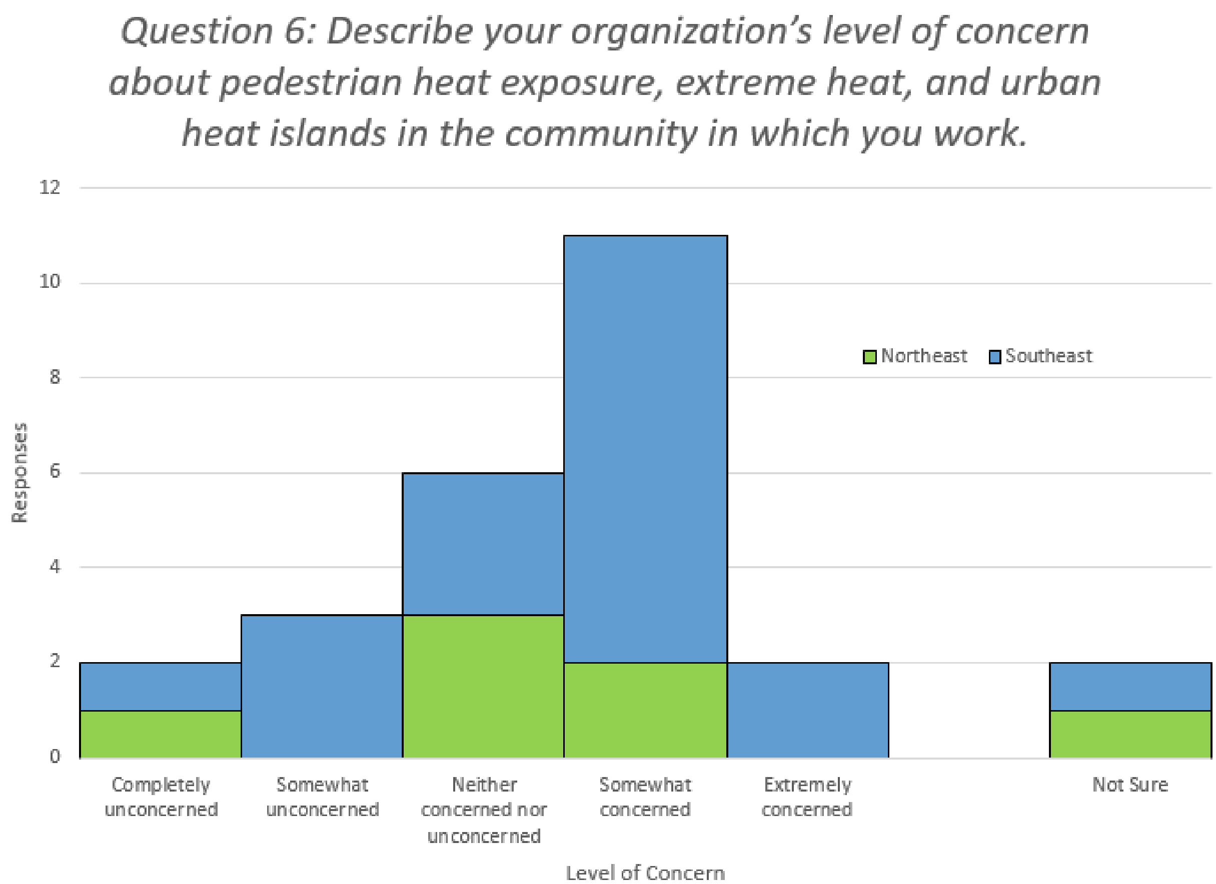

Figure 11. Responses to Question 6: Describe your organization's level of concern about pedestrian heat exposure, extreme heat, and urban heat islands in the community in which you work.

Only two of 25 responses, both in the southeast region, reported that they are aware of any issues surrounding pedestrian thermal comfort in their regions. Likewise, the survey asked respondents to rate the severity of thermal discomfort for vulnerable pedestrian groups in their jurisdictions. The most common response was 3 out of 5 (moderately severe), but there were only two responses higher than 3 out of 5. While the responses for the Northeast reinforce the theory that heat mitigation is not perceived as a high priority for the majority of transportation planners and engineers, the responses from the Southeast indicate a high level of disagreement about the relative importance of the issue, particularly for vulnerable populations. Figure 12 shows the response distribution.

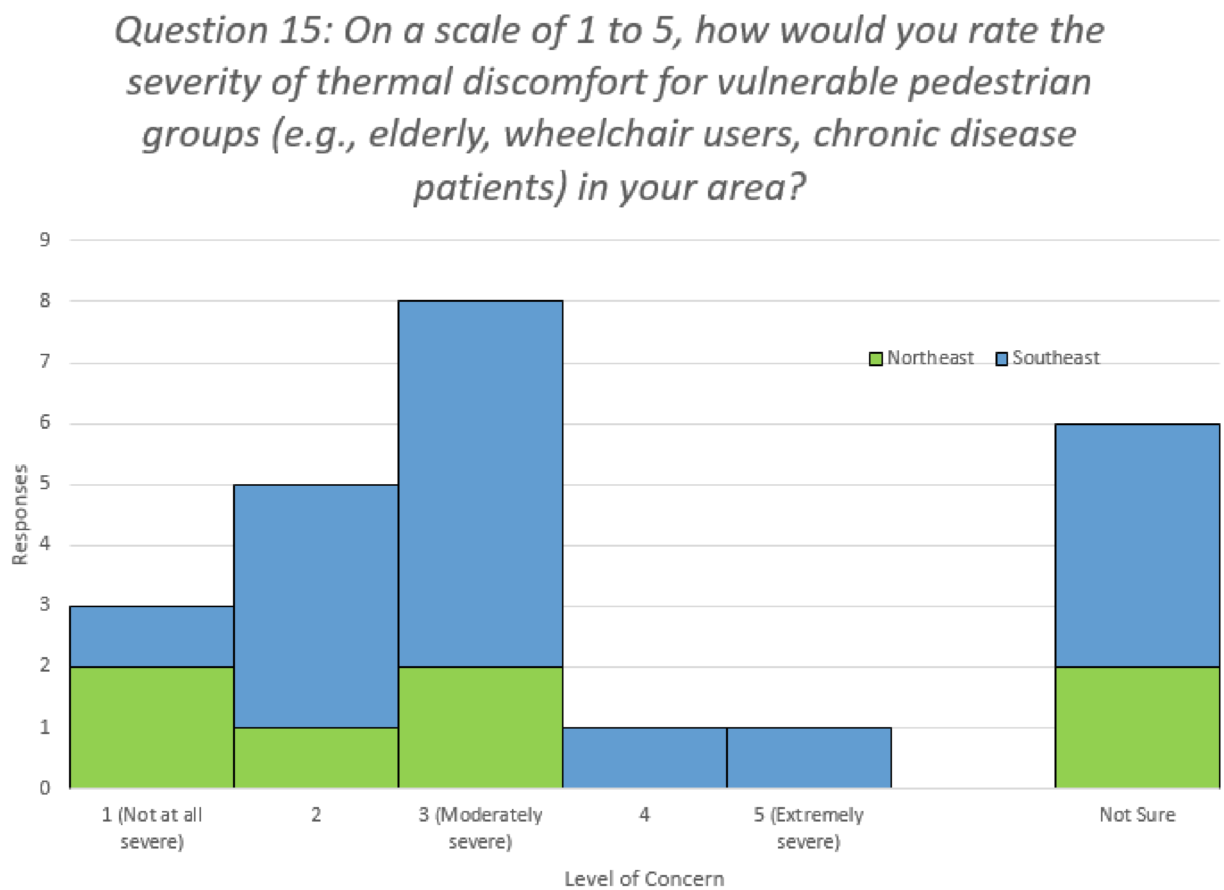

Figure 12. Responses to Question 15: On a scale of 1 to 5, how would you rate the severity of thermal discomfort for vulnerable pedestrian groups (e.g., elderly, wheelchair users, chronic disease patients) in your area?

3.3.3.2 Strategies to Mitigate Urban Heat

The survey asked respondents the following question, to assess their personal experiences with heat mitigation:

> *Question 7: In what ways does your current role in the organization allow you or your team to mitigate the impacts of extreme heat and urban heat islands?*

Selected responses to question 7 from the northeast region are included below:

1. Maine planner: *"Maine does not have a big concern for heat mitigation. We are more concerned about pedestrian safety, utilizing sidewalks to narrow roadways and provide walkable downtowns to promote economic growth and viability."*
2. Vermont planner: *"The public has expressed interest in retaining or adding street trees in our conceptual plan designs for sidewalk, path, and roadway projects as a way to provide shade. Greenbelts are also important components for storm water management, snow storage, and as a buffer between vehicles and people."*

3. Vermont planner: *"As a transportation planner, we can start to make considerations of the impacts of extreme heat in our communities through pedestrian-related scoping studies."*
4. Vermont planner: *"we could present the opportunity to municipalities building projects, but we would have no control over the decisions those municipalities take."*

Response 1 notes that heat mitigation is not a priority in Maine, likely because of the perception that the northeast has a relatively mild summer climate. The response lists safety, walkability, and economic development as higher priorities. On the other hand, Response 2 notes a public desire for planting street trees to provide shade, providing some evidence that heat mitigation is desired by the public, even in the northeast. Responses 3 and 4 use the words "can" and "could" to describe their heat mitigation capabilities, suggesting that these strategies aren't actually being employed. Response 4 notes that their planning agency ultimately does not have the power to mandate heat mitigation at the municipal level though their influence on decision making may be significant.

Likewise, selected responses to question 7 from the southeast region are listed below:

5. Georgia planner: *"We primarily interface on the project development and grant writing/administration side of projects. As granting agencies encourage use of such alternative paving methods by rewarding points for sustainability, resilience, or innovation, it becomes easier to promote such materials and techniques."*
6. Georgia engineer: *"Our parking lot provisions require tree islands every 12 spaces. It's not much, but it's a step in the right direction!"*
7. Georgia engineer: *"On one project, we specified concrete pavers for the surface of a dock at a boat ramp. Our goals were to mitigate heat for boaters using the dock, and to use a long-lasting material."*

Response 5 provides evidence that incentivizing heat mitigation through the implementation of requirements in grant funding applications may be an effective tool for encouraging heat mitigation. As previously discussed survey responses have revealed, municipalities often cite cost as an influential factor in pedestrian infrastructure design and construction decisions. Likewise, grant funding is a common source of funding for pedestrian infrastructure (see Section 4.2.2). These responses suggest that municipalities would be more inclined to use alternative materials or design techniques if they were incentivized or required by grant funds. Similarly, response 6 reveals that regulatory requirements may be another way to encourage heat mitigation.

Response 7 describes an instance in which an alternative material was used with the purpose of heat mitigation, but also notes that durability was a priority as well. The prioritization of material performance has also been noted by other responses in previously discussed questions (see Section 4.1.1). These responses suggest that alternative materials that sacrifice functionality or durability in exchange for heat mitigation are less likely to achieve widespread adoption.

Respondents were also asked the following questions to gain insight into any previous or ongoing organizational actions taken to mitigate urban heat:

> *Question 16: What actions or policies has your organization taken to date to improve thermal comfort for pedestrians during extreme heat events?*
>
> *Question 17: Are there specific projects or initiatives in your area that are aimed at protecting vulnerable pedestrian groups from the effects of urban heat?*

Only four out of 21 respondents were able to cite actions or policies taken by their organization or by other organizations in their area to mitigate heat. Selected responses to question 16 are included below:

1. Maine planner: *"There's not a need for this."*
2. Georgia planner: *"No formal actions as the final decisions are beyond our scope of responsibility or influence. We do inform local governments of options as appropriate."*
3. Georgia planner: *"Connect with other organizations who can provide resources and advocate for policies to mitigate impacts of extreme heat."*
4. Georgia engineer: *"Installed pocket parks. Covered park bench areas."*
5. Georgia engineer: *"Shade structures along some pedestrian routes; tree canopy."*

Once again, response 1 indicates that there may not be a perceived need for heat mitigation among planners in the northeast. Response 2 also echoes the sentiment expressed by the Vermonter planner in response 4 of question 7; planners may feel that they can make suggestions but ultimately do not have final control over the implementation of heat mitigation measures. Response 3 further reinforces the theory that heat mitigation measure might best be encouraged through funding incentives and/or policy requirements.

3.3.4 Assessing the Barriers Preventing the Implementation of Alternative Materials and Green Stormwater Infrastructure

A number of potential barriers may be preventing more widespread implementation of alternative pedestrian infrastructure materials and design techniques. This section will discuss each potential factor individually to assess the influence of that factor in decision-making.

3.3.4.1 Awareness

Awareness of alternative materials is likely a prerequisite for their adoption, therefore a general lack of awareness of alternative pedestrian infrastructure materials is likely to be a factor preventing their widespread use. Within the sampled population, roughly two-thirds of all survey respondents displayed an awareness of alternative paving materials. However, less than half of those respondents had used alternative paving materials in the past. This suggests that over half of those that are aware of alternative paving materials gained their awareness independently, not necessarily through the actions of their organization. If this is the case, then it can be assumed that the two-thirds of engineers and planners with an awareness of alternative paving materials are likely to be well-distributed across organizations (as opposed to being clustered in a subset of organizations that have had direct experience with those materials). If that knowledge is well distributed throughout the broader population of engineers and planners, than it is likely that most engineering and planning organizations have at least one employee on staff that is aware of alternative paving materials. As such, it is unlikely that a general lack of awareness is substantially limiting the use of alternative paving materials.

On the other hand, only two-fifths of respondents reported an awareness of alternative design or construction techniques, such as the incorporation of green stormwater infrastructure. From this data, it is more reasonable to infer that lack of awareness may be limiting the use of green stormwater infrastructure. Additional research is warranted to investigate this further.

3.3.4.2 Costs and Financing

The most commonly reported factor influencing the prioritization of infrastructure projects was costs / financing. One engineer from Georgia noted, “Cost is a major concern in the decision-making process. Unless directly incentivized otherwise, the general expectation is to use the most affordable products.” Likewise, one planner from Florida stated, “Asking engineers to include [smart surface treatments] in roadway projects is met with "not in the scope/budget" responses. The smart surface treatments are an afterthought, not a priority for city engineers.” A substantial number of responses echoed these sentiments. As such, financial factors are seemingly a highly influential factor discouraging more widespread use of alternative pedestrian infrastructure materials and design techniques.

Notably, a substantial number of respondents reportedly rely on grant funding for at least a portion of their pedestrian infrastructure funding. There may be an opportunity for grant funding agencies to set aside funds specifically for projects incorporating alternative materials or design techniques, thereby encouraging more widespread usage.

3.3.4.3 Material Properties

Many survey responses alluded to various material properties as a consideration in the selection of materials. One municipal employee in Florida noted that they “Frequently have utility trucks parking on the sidewalks utilizing outriggers.” As such, their sidewalks must be capable of bearing weight. Several other responses cited durability, longevity, and/or maintenance needs as desirable material properties. Likewise, some respondents reported a need to ensure ADA compliance by providing smooth, firm walking surfaces. All else equal, it seems likely that engineers and planners would prioritize these factors over heat mitigation potential. Therefore, alternative paving materials that sacrifice durability or accessibility are unlikely to see widespread use.

3.3.4.4 Asset Management

Less than half of respondents indicated that their community has a pedestrian infrastructure asset management system in place. The communities that do have a pedestrian infrastructure asset management system in place appear to have a higher likelihood of using alternative materials or design techniques. It is possible that the presence of an asset management system allows communities to make more thoughtful decisions about design alternatives for pedestrian infrastructure projects. On the other hand, there is an administrative burden associated with the implementation of an asset management system, so it is possible that the communities who have implemented asset management systems have done so because they have more capacity, and that capacity has also contributed to an increased usage of alternative design techniques. Further research would be required to determine the presence of a causal relationship between these factors. Regardless, survey respondents did not report asset management related issues as a hindrance preventing the use of alternative materials or designs.

3.3.4.5 Prioritization / Perceived Need

The survey responses indicate that heat mitigation is prioritized to a low degree by most planning and engineering organizations. Regionally, despite a high degree of disagreement about the impact of extreme heat on the thermal comfort of users, there seems to be a greater perceived need to address heat related concerns in the southeast as opposed to the northeast where concern is generally lower. When asked, most planners and engineers were "somewhat concerned" about the effects of urban heat, but those concerns are seemingly outweighed by other factors, such as cost. Some responses from the northeast region reported that there simply isn't a need for heat mitigation in their jurisdictions, though other responses from both the northeast and southeast regions mentioned receiving requests from the public for heat mitigation measures, such as shade. Ultimately, the relative lack of perceived need for heat mitigation measures causes a greater focus to be placed on other concerns, such as cost or material properties.

3.3.4.6 Policy Implications

Several survey responses reference various policies as an influential factor in design choices. One planner from Vermont noted that, "decisions [are] limited by state and federal regulations and standards." Another planner in Vermont reported that municipal public works standards currently mandate the use of concrete or asphalt. Similarly, a planner from Florida noted that local zoning ordinances can both encourage and prevent the use of alternative materials, depending on the area. Pedestrian infrastructure must meet ADA design and condition requirements. Any overly-prescriptive policies, regulations, or design standards that mandate the use of specific materials could prevent municipalities from considering and advocating for appropriate alternatives. As such, policy compliance may be an important factor currently preventing more widespread use of alternative materials and design techniques. Additional research into the harmonization of current design standards with new proposed systems and emerging threats to public health and changing climates should be conducted.

CHAPTER 4. CONCLUSIONS

There is growing awareness across federal agencies of the risk from and need to address built environment driven heat exposure disparities including in joint initiatives like the National Integrated Heat Health Information Service (NIHHIS) which operates "Heat.gov" and is run by the US Centers for Disease Control and the US National Oceanic and Atmospheric Administration, or the US Environmental Protection Agency's "Cool Communities" program, among others. While UHI has generally been studied and treated at the city-level, the pervasive nature of the problem across the urban-rural spectrum and in communities across the country suggest that systemic action is necessary to mitigate the effects of the rapidly warming climate, particularly for vulnerable populations. Systemic action will necessarily include participation by practitioners across different sectors of the economy including those in transportation, the infrastructure for which contributes significantly to the drivers of the UHI phenomenon. There are a suite of federal and national resources, policies and engineering and design guidance available from state pedestrian agencies to support municipalities in the design and implementation of sidewalk infrastructure projects. The sidewalk specific standard drawings available from the state of Vermont, for example, are focused on ramps, and intersection designs and are only provided for Portland cement concrete with standard design parameters including thickness. Federal and national resources including from the Federal Highway Administration (FHWA) are available that encourage flexibility with regards to pedestrian and bicycle infrastructure design but do not specifically reference urban heat micro-environment reduction as a recommended area of consideration.

Based on the reviewed literature which was constrained to studies published between 2019 and 2023, some material components such as novel aggregates show promising results in laboratory experiments, suggesting a TRL 3-4; however, additional materials such as permeable pavements are likely at TRL 7-8. For materials and designs that are at higher levels of technology readiness, further evaluation across both efficacy, durability and maintenance would be required to characterize the materials as fully ready for widespread adoption (TRL9) and while evident, this information was also the most limited within the reviewed literature. Furthermore, evaluation of the emissions impacts over the full lifecycle was limited.

This study has surveyed a diverse group of transportation planners and engineers, as well as reviewed existing literature, to identify and assess the factors influencing the use of alternative paving materials and green stormwater infrastructure design techniques in pedestrian infrastructure projects. The leading factors preventing the widespread implementation of alternative pavement materials and green stormwater infrastructure are financial concerns, policy requirements, and the prioritization of other design considerations over heat mitigation. Survey respondents note that they are generally expected to use the most affordable materials, which often eliminates alternative materials from consideration. Further, local, state, and federal regulations, policies, and design standards can restrict an organization's options when considering alternatives. Survey respondents tended to prioritize other factors, such as material durability and functionality, over material heat mitigation capacity. The survey responses indicate two potential strategies for encouraging more widespread use of alternative paving materials or green stormwater infrastructure—incentivize their use through grant funding and/or stipulate their use through regulation.

Because respondents who were aware of alternative materials and designs were often aware of multiple options (e.g., permeable pavements and street trees), decision-support tools that allow practitioners to evaluate design and criteria tradeoffs are needed. Evidence of such tools was present within the reviewed literature; however, being outside the scope of this study, evaluation of the efficacy and adoption of such tools is needed, particularly in the context of municipal capacity which can vary significantly between and across communities.

REFERENCES

1. Fechter-Leggett, E. D., A. Vaidyanathan, and E. Choudhary. Heat Stress Illness Emergency Department Visits in National Environmental Public Health Tracking States, 2005-2010. *Journal of Community Health*, Vol. 41, No. 1, 2016, pp. 57–69. https://doi.org/10.1007/s10900-015-0064-7.
2. Vaidyanathan, A. Heat-Related Deaths — United States, 2004–2018. *MMWR. Morbidity and Mortality Weekly Report*, Vol. 69, 2020. https://doi.org/10.15585/mmwr.mm6924a1.
3. U.S. Department of Commerce, N. Weather Related Fatality and Injury Statistics. https://www.weather.gov/hazstat/. Accessed Jul. 26, 2021.
4. IPCC. *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Geneva, Switzerland, 2014.
5. Vanos, J. K., L. S. Kalkstein, and T. J. Sanford. Detecting Synoptic Warming Trends across the US Midwest and Implications to Human Health and Heat-Related Mortality. *International Journal of Climatology*, Vol. 35, No. 1, 2015, pp. 85–96. https://doi.org/10.1002/joc.3964.
6. Vanos, J., G. Guzman-Echavarria, J. W. Baldwin, C. Bongers, K. L. Ebi, and O. Jay. A Physiological Approach for Assessing Human Survivability and Liveability to Heat in a Changing Climate. *Nature Communications*, Vol. 14, No. 1, 2023, p. 7653. https://doi.org/10.1038/s41467-023-43121-5.
7. Vecellio, D. J., and J. K. Vanos. Aligning Thermal Physiology and Biometeorological Research for Heat Adaptation and Resilience in a Changing Climate. *Journal of Applied Physiology*, 2024. https://doi.org/10.1152/japplphysiol.00098.2024.
8. Vecellio, D. J., M. Huber, and W. L. Kenney. Why Not 35°C? Reasons for Reductions in Limits of Human Thermal Tolerance and Their Implications. *Temperature*, Vol. 0, No. 0, pp. 1–3. https://doi.org/10.1080/23328940.2024.2399952.
9. Howard, L. *The Climate of London Deduced from Meteorological Observations Made in the Metropolis and at Various Places around It [Electronic Resource]*. Harvey and Darton, London, 1833.
10. Oke, T. R. The Energetic Basis of the Urban Heat Island. *Quarterly Journal of the Royal Meteorological Society*, Vol. 108, No. 455, 1982, pp. 1–24. https://doi.org/10.1002/qj.49710845502.
11. Phelan, P. E., K. Kaloush, M. Miner, J. Golden, B. Phelan, H. Silva, and R. A. Taylor. Urban Heat Island: Mechanisms, Implications, and Possible Remedies. *Annual Review of Environment and Resources*, Vol. 40, No. 1, 2015, pp. 285–307. https://doi.org/10.1146/annurev-environ-102014-021155.
12. Voogt, J. How Researchers Measure Urban Heat Islands. Department of Geography, University of Western Ontario, London ON, Canada.

13. Cosgrove, A., and M. Berkelhammer. Downwind Footprint of an Urban Heat Island on Air and Lake Temperatures. *npj Climate and Atmospheric Science*, Vol. 1, No. 1, 2018, pp. 1–10. https://doi.org/10.1038/s41612-018-0055-3.
14. Shepherd, J. M. A Review of Current Investigations of Urban-Induced Rainfall and Recommendations for the Future. 2005. https://doi.org/10.1175/EI156.1.
15. Organization (WMO), W. M. Initial Guidance to Obtain Representative Meteorological Observations at Urban Sites. https://library.wmo.int/records/item/35333-initial-guidance-to-obtain-representative-meteorological-observations-at-urban-sites. Accessed Nov. 22, 2023.
16. Shandas, V., Voelkel, Williams, and Hoffman. Integrating Satellite and Ground Measurements for Predicting Locations of Extreme Urban Heat. *Climate*, Vol. 7, No. 1, 2019. https://doi.org/10.3390/cli7010005.
17. Vujovic, S., B. Haddad, H. Karaky, N. Sebaibi, and M. Boutouil. Urban Heat Island: Causes, Consequences, and Mitigation Measures with Emphasis on Reflective and Permeable Pavements. *CivilEng*, Vol. 2, No. 2, 2021, pp. 459–484.
18. Middel, A., S. AlKhaled, F. A. Schneider, B. Hagen, and P. Coseo. 50 Grades of Shade. *Bulletin of the American Meteorological Society*, Vol. 102, No. 9, 2021, pp. E1805–E1820. https://doi.org/10.1175/BAMS-D-20-0193.1.
19. Kim, Y. J., and R. D. Brown. A Multilevel Approach for Assessing the Effects of Microclimatic Urban Design on Pedestrian Thermal Comfort: The High Line in New York. *Building and Environment*, Vol. 205, 2021, p. 108244.
20. Zhang, Y., Y. Wang, N. Ding, and X. Yang. Spatial Pattern Impact of Impervious Surface Density on Urban Heat Island Effect: A Case Study in Xuzhou, China. *Land*, Vol. 11, No. 12, 2022, p. 2135. https://doi.org/10.3390/land11122135.
21. Santamouris, M. On the Energy Impact of Urban Heat Island and Global Warming on Buildings. *Energy and Buildings*, Vol. 82, 2014, pp. 100–113. https://doi.org/10.1016/j.enbuild.2014.07.022.
22. Hao, L., X. Huang, M. Qin, Y. Liu, W. Li, and G. Sun. Ecohydrological Processes Explain Urban Dry Island Effects in a Wet Region, Southern China. *Water Resources Research*, Vol. 54, No. 9, 2018, pp. 6757–6771. https://doi.org/10.1029/2018WR023002.
23. Wang, Y., Z. Guo, and J. Han. The Relationship between Urban Heat Island and Air Pollutants and Them with Influencing Factors in the Yangtze River Delta, China. *Ecological Indicators*, Vol. 129, 2021, p. 107976. https://doi.org/10.1016/j.ecolind.2021.107976.
24. Ulpiani, G. On the Linkage between Urban Heat Island and Urban Pollution Island: Three-Decade Literature Review towards a Conceptual Framework. *The Science of the Total Environment*, Vol. 751, 2021, p. 141727. https://doi.org/10.1016/j.scitotenv.2020.141727.
25. United Nations, Department of Economic and Social Affairs, and Population Division. *World Population Prospects Highlights, 2019 Revision Highlights, 2019 Revision*. 2019.

26. Tuholske, C., K. Caylor, C. Funk, A. Verdin, S. Sweeney, K. Grace, P. Peterson, and T. Evans. Global Urban Population Exposure to Extreme Heat. *Proceedings of the National Academy of Sciences (PNAS)*, Vol. 118, No. 41, 2021. https://doi.org/10.1073/pnas.2024792118.
27. Kalnay, E., and M. Cai. Impact of Urbanization and Land-Use Change on Climate. *Nature*, Vol. 423, No. 6939, 2003, pp. 528–531. https://doi.org/10.1038/nature01675.
28. Cheela, V. S., M. John, W. Biswas, and P. Sarker. Combating Urban Heat Island Effect—A Review of Reflective Pavements and Tree Shading Strategies. *Buildings*, Vol. 11, No. 3, 2021, p. 93.
29. Antonczak, B., E. M. B. Doran, and G. Rowangould. A High-Resolution Population Exposure-Based Approach for Evaluating the Impacts of Transportation Infrastructure on Excessive Heat Microenvironments. Presented at the National Academy of Sciences Transportation Research Board Annual Meeting, Washington, D.C., 2023.
30. Antonczak, B., P. King, G. Rowangould, and E. M. B. Doran. Heat Exposure Mitigation Through Pavement Reduction Scenarios. Presented at the International Congress of Biometeorology, Tempe, AZ, 2023.
31. NOAA. 2023 Was the World's Warmest Year on Record, by Far. *National Oceanic and Atmospheric Administration*. https://www.noaa.gov/news/2023-was-worlds-warmest-year-on-record-by-far. Accessed Apr. 4, 2024.
32. Andrew, R. M. Global CO2 Emissions from Cement Production. 2018, p. 23.
33. Shacat, J., J. R. Willis, and B. Ciavola. *GHG Emissions Inventory for Asphalt Mix Production In the United States: Current Industry Practices and Opportunities to Reduce Future Emissions*. National Asphalt Pavement Association, Greenbelt, MD, 2022, p. 34.
34. Stewart, I. D., and T. R. Oke. Local Climate Zones for Urban Temperature Studies. *Bulletin of the American Meteorological Society*, Vol. 93, No. 12, 2012, pp. 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1.
35. Qin, Y., and J. E. Hiller. Understanding Pavement-Surface Energy Balance and Its Implications on Cool Pavement Development. *Energy and Buildings*, Vol. 85, 2014, pp. 389–399. https://doi.org/10.1016/j.enbuild.2014.09.076.
36. Wang, C., Z.-H. Wang, K. E. Kaloush, and J. Shacat. Cool Pavements for Urban Heat Island Mitigation: A Synthetic Review. *Renewable and Sustainable Energy Reviews*, Vol. 146, 2021, p. 111171. https://doi.org/10.1016/j.rser.2021.111171.
37. Santamouris, M. Using Cool Pavements as a Mitigation Strategy to Fight Urban Heat Island—A Review of the Actual Developments. *Renewable and Sustainable Energy Reviews*, Vol. 26, 2013, pp. 224–240. https://doi.org/10.1016/j.rser.2013.05.047.
38. U.S. Environmental Protection Agency. *Cool Pavements*. U.S. Environmental Protection Agency, 2012.

39. Qin, Y. A Review on the Development of Cool Pavements to Mitigate Urban Heat Island Effect. *Renewable and Sustainable Energy Reviews*, Vol. 52, 2015, pp. 445–459. https://doi.org/10.1016/j.rser.2015.07.177.
40. Melnikov, V. R., G. I. Christopoulos, V. V. Krzhizhanovskaya, M. H. Lees, and P. M. A. Sloot. Behavioural Thermal Regulation Explains Pedestrian Path Choices in Hot Urban Environments. *Scientific Reports*, Vol. 12, No. 1, 2022, p. 2441. https://doi.org/10.1038/s41598-022-06383-5.
41. Pereira, C., I. Flores-Colen, and M. P. Mendes. Guidelines to Reduce the Effects of Urban Heat in a Changing Climate: Green Infrastructures and Design Measures. *Sustainable Development*, Vol. 32, No. 1, 2024, pp. 57–83. https://doi.org/10.1002/sd.2646.
42. Coughlin, J. P., C. D. Campbell, and D. C. Mays. Infiltration and Clogging by Sand and Clay in a Pervious Concrete Pavement System. *Journal of Hydrologic Engineering*, Vol. 17, No. 1, 2012, pp. 68–73. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000424.
43. Bretz, S., H. Akbari, and A. Rosenfeld. Practical Issues for Using Solar-Reflective Materials to Mitigate Urban Heat Islands. *Atmospheric Environment*, Vol. 32, No. 1, 1998, pp. 95–101. https://doi.org/10.1016/S1352-2310(97)00182-9.
44. USEPA. *National Management Measures to Control Nonpoint Source Pollution from Urban Areas*. Publication EPA 430-F-05-004. United States Environmental Protection Agency, Washington, D.C., 2005.
45. Chen, J., H. Dan, Y. Ding, Y. Gao, M. Guo, S. Guo, B. Han, B. Hong, Y. Hou, C. Hu, J. Hu, J. Huyan, J. Jiang, W. Jiang, C. Li, P. Liu, Y. Liu, Z. Liu, G. Lu, J. Ouyang, X. Qu, D. Ren, C. Wang, C. Wang, D. Wang, D. Wang, H. Wang, H. Wang, Y. Xiao, C. Xing, H. Xu, Y. Yan, X. Yang, L. You, Z. You, B. Yu, H. Yu, H. Yu, H. Zhang, J. Zhang, C. Zhou, C. Zhou, and X. Zhu. New Innovations in Pavement Materials and Engineering: A Review on Pavement Engineering Research 2021. *Journal of Traffic and Transportation Engineering (English Edition)*, Vol. 8, No. 6, 2021, pp. 815–999. https://doi.org/10.1016/j.jtte.2021.10.001.
46. Wang, R., M. J. Eckelman, and J. B. Zimmerman. Consequential Environmental and Economic Life Cycle Assessment of Green and Gray Stormwater Infrastructures for Combined Sewer Systems. *Environmental Science & Technology*, Vol. 47, No. 19, 2013, pp. 11189–11198. https://doi.org/10.1021/es4026547.
47. Oberndorfer, E., J. Lundholm, B. Bass, R. R. Coffman, H. Doshi, N. Dunnett, S. Gaffin, M. Köhler, K. K. Y. Liu, and B. Rowe. Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. *BioScience*, Vol. 57, No. 10, 2007, pp. 823–833. https://doi.org/10.1641/B571005.
48. Suppakittpaisarn, P., X. Jiang, and W. C. Sullivan. Green Infrastructure, Green Stormwater Infrastructure, and Human Health: A Review. *Current Landscape Ecology Reports*, Vol. 2, No. 4, 2017, pp. 96–110. https://doi.org/10.1007/s40823-017-0028-y.
49. Templier, M., and G. Paré. A Framework for Guiding and Evaluating Literature Reviews. *Communications of the Association for Information Systems*, Vol. 37, No. 1, 2015. https://doi.org/10.17705/1CAIS.03706.

50. Selçuk, A. A. A Guide for Systematic Reviews: PRISMA. *Turkish Archives of Otorhinolaryngology*, Vol. 57, No. 1, 2019, p. 57. https://doi.org/10.5152/tao.2019.4058.

51. Shamsaei, M., A. Carter, and M. Vaillancourt. A Review on the Heat Transfer in Asphalt Pavements and Urban Heat Island Mitigation Methods. *Construction and Building Materials*, Vol. 359, 2022, p. 129350. https://doi.org/10.1016/j.conbuildmat.2022.129350.

52. Al-Humairi, S. F. I., A. H. Alias, N. A. Haron, S. Hassim, and F. M. Jakarni. Sustainable Pavement: A Review on the Usage of Pavement as a Mitigation Strategy for UHI. No. 1075, 2021, pp. 012010.

53. Bartesaghi Koc, C., P. Osmond, and A. Peters. Evaluating the Cooling Effects of Green Infrastructure: A Systematic Review of Methods, Indicators and Data Sources. *Solar Energy*, Vol. 166, 2018, pp. 486–508. https://doi.org/10.1016/j.solener.2018.03.008.

54. Balany, F., A. W. M. Ng, N. Muttil, S. Muthukumaran, and M. S. Wong. Green Infrastructure as an Urban Heat Island Mitigation Strategy-A Review. *Water*, Vol. 12, No. 12, 2020, p. 3577. https://doi.org/10.3390/w12123577.

55. Seifeddine, K., S. Amziane, and E. Toussaint. Thermal Behavior of Pervious Concrete in Dry Conditions. *Construction and Building Materials*, Vol. 345, 2022, p. 128300. https://doi.org/10.1016/j.conbuildmat.2022.128300.

56. Chen, Y., L. Lyu, J. Pei, G. Zhang, Y. Wen, and J. Zhang. Novel Asphalt-Mix Design with High Thermal Diffusivity for Alleviating the Urban Heat Island. *Journal of Materials in Civil Engineering*, Vol. 32, No. 11, 2020, p. 04020321.

57. Du, Y., M. Dai, H. Deng, D. Deng, T. Wei, and L. Kong. Laboratory Investigation on Thermal and Road Performances of Asphalt Mixture Containing Glass Microsphere. *Construction and Building Materials*, Vol. 264, 2020, p. 120710.

58. Du, Y., M. Dai, H. Deng, D. Deng, T. Wei, and W. Li. Evaluation of Thermal and Anti-Rutting Behaviors of Thermal Resistance Asphalt Pavement with Glass Microsphere. *Construction and Building Materials*, Vol. 263, 2020, p. 120609.

59. Pucher, B., I. Zluwa, P. Spörl, U. Pitha, and G. Langergraber. Evaluation of the Multifunctionality of a Vertical Greening System Using Different Irrigation Strategies on Cooling, Plant Development and Greywater Use. *Science of The Total Environment*, Vol. 849, 2022, p. 157842. https://doi.org/10.1016/j.scitotenv.2022.157842.

60. Atta-Boateng, A., G. P. Berlyn, C. S. O'Hern, and A. J. Felson. Suitability of Wetland Macrophyte in Green Cooling Tower Performance. *Ecological Engineering*, Vol. 127, 2019, pp. 487–493. https://doi.org/10.1016/j.ecoleng.2018.08.002.

61. Shi, D., J. Song, J. Huang, C. Zhuang, R. Guo, and Y. Gao. Synergistic Cooling Effects (SCEs) of Urban Green-Blue Spaces on Local Thermal Environment: A Case Study in Chongqing, China. *Sustainable Cities and Society*, Vol. 55, 2020, p. 102065. https://doi.org/10.1016/j.scs.2020.102065.

62. Chàfer, M., A. L. Pisello, C. Piselli, and L. F. Cabeza. Greenery System for Cooling down Outdoor Spaces: Results of an Experimental Study. *Sustainability*, Vol. 12, No. 15, 2020, p. 5888.

63. Shahjahan, A. T. M., K. S. Ahmed, and I. B. Said. Study on Riparian Shading Envelope for Wetlands to Create Desirable Urban Bioclimates. *Atmosphere*, Vol. 11, No. 12, 2020, p. 1348. https://doi.org/10.3390/atmos11121348.

64. Balany, F., N. Muttil, S. Muthukumaran, M. S. Wong, and A. W. M. Ng. Studying the Effect of Blue-Green Infrastructure on Microclimate and Human Thermal Comfort in Melbourne's Central Business District. *Sustainability*, Vol. 14, No. 15, 2022, p. 9057. https://doi.org/10.3390/su14159057.

65. Ouyang, W., T. Sinsel, H. Simon, T. E. Morakinyo, H. Liu, and E. Ng. Evaluating the Thermal-Radiative Performance of ENVI-Met Model for Green Infrastructure Typologies: Experience from a Subtropical Climate. *Building and Environment*, Vol. 207, 2022, p. 108427. https://doi.org/10.1016/j.buildenv.2021.108427.

66. Wiegels, R., F. Chapa, and J. Hack. High Resolution Modeling of the Impact of Urbanization and Green Infrastructure on the Water and Energy Balance. *Urban Climate*, Vol. 39, 2021, p. 100961. https://doi.org/10.1016/j.uclim.2021.100961.

67. Zhu, Z., D. Zhou, Y. Wang, D. Ma, and X. Meng. Assessment of Urban Surface and Canopy Cooling Strategies in High-Rise Residential Communities. *Journal of Cleaner Production*, Vol. 288, 2021, p. 125599. https://doi.org/10.1016/j.jclepro.2020.125599.

68. Jung, M. C., K. Dyson, and M. Alberti. Urban Landscape Heterogeneity Influences the Relationship between Tree Canopy and Land Surface Temperature. *Urban Forestry & Urban Greening*, Vol. 57, 2021, p. 126930. https://doi.org/10.1016/j.ufug.2020.126930.

69. Tran, T. J., M. R. Helmus, and J. E. Behm. Green Infrastructure Space and Traits (GIST) Model: Integrating Green Infrastructure Spatial Placement and Plant Traits to Maximize Multifunctionality. *Urban Forestry & Urban Greening*, Vol. 49, 2020, p. 126635. https://doi.org/10.1016/j.ufug.2020.126635.

70. Wang, X., S. Miao, H. Liu, J. Sun, N. Zhang, and J. Zou. Assessing the Impact of Urban Hydrological Processes on the Summertime Urban Climate in Nanjing Using the WRF Model. *Journal of Geophysical Research-Atmospheres*, Vol. 124, No. 23, 2019, pp. 12683–12707. https://doi.org/10.1029/2019JD030674.

71. Anderson, V., and W. A. Gough. A Typology of Nature-Based Solutions for Sustainable Development: An Analysis of Form, Function, Nomenclature, and Associated Applications. *Land*, Vol. 11, No. 7, 2022, p. 1072. https://doi.org/10.3390/land11071072.

72. Norton, B. A., A. M. Coutts, S. J. Livesley, R. J. Harris, A. M. Hunter, and N. S. G. Williams. Planning for Cooler Cities: A Framework to Prioritise Green Infrastructure to Mitigate High Temperatures in Urban Landscapes. *Landscape and Urban Planning*, Vol. 134, 2015, pp. 127–138. https://doi.org/10.1016/j.landurbplan.2014.10.018.

73. Meerow, S., M. Natarajan, and D. Krantz. Green Infrastructure Performance in Arid and Semi-Arid Urban Environments. *Urban Water Journal*, Vol. 18, No. 4, 2021, pp. 275–285. https://doi.org/10.1080/1573062X.2021.1877741.

74. Leonard, L., B. Miles, B. Heidari, L. Lin, A. M. Castronova, B. Minsker, J. Lee, C. Scaife, and L. E. Band. Development of a Participatory Green Infrastructure Design, Visualization and Evaluation System in a Cloud Supported Jupyter Notebook Computing Environment. *Environmental Modelling & Software*, Vol. 111, 2019, pp. 121–133. https://doi.org/10.1016/j.envsoft.2018.10.003.

75. GAO. *Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects*. Publication GAO-20-48G. U.S. Government Accountability Office, 2020, p. 144.

76. Sheppard, V. *Research Methods for the Social Sciences: An Introduction*. 2020.

77. Regmi, P. R., E. Waithaka, A. Paudyal, P. Simkhada, and E. van Teijlingen. Guide to the Design and Application of Online Questionnaire Surveys. *Nepal Journal of Epidemiology*, Vol. 6, No. 4, 2016, pp. 640–644. https://doi.org/10.3126/nje.v6i4.17258.

78. Pelz. Chapter 9 Survey Research | Research Methods for the Social Sciences. https://courses.lumenlearning.com/suny-hccc-research-methods/chapter/chapter-9-survey-research/. Accessed Oct. 28, 2024.

79. Sammut, R., O. Griscti, and I. J. Norman. Strategies to Improve Response Rates to Web Surveys: A Literature Review. *International Journal of Nursing Studies*, Vol. 123, 2021, p. 104058. https://doi.org/10.1016/j.ijnurstu.2021.104058.

80. Wu, M.-J., K. Zhao, and F. Fils-Aime. Response Rates of Online Surveys in Published Research: A Meta-Analysis. *Computers in Human Behavior Reports*, Vol. 7, 2022, p. 100206. https://doi.org/10.1016/j.chbr.2022.100206.

DATA SUMMARY

Products of Research

The survey results represent the opinions of the agencies surveyed, and not the opinions of any individual participants in the survey. As such, individual respondent names were removed from the survey data, and any comments provided by respondents have been edited to remove any personally-identifiable information. To further protect the identities of individual respondents, survey data made available to the public were tabulated for all agencies (individual agency responses are not shown). The Qualtrics survey results were ported into an Excel spreadsheet that contains aggregate survey response data. The spreadsheet can be downloaded from the Zenodo repository at: https://zenodo.org/records/14018709.

Data Format and Content

The survey data can be downloaded from the Zenodo link provided above. The survey mechanism is provided as an Appendix to this report, and all survey results are stored for each response enumeration in the Excel spreadsheet identified above.

Data Access and Sharing

There are no restrictions to data access or sharing.

Reuse and Redistribution

There are no restrictions to reuse or redistribution.

APPENDIX A: QUALTRICS SURVEY INSTRUMENT

Question 1a. What state, county, city, local government, or other organization do you work for?

1b. How many sidewalk projects are you (and/or your department or unit) typically involved with during a year?

1c. What is your current title?

1d. How many years have you worked at your organization (please round to the nearest whole number)?

Question 2a. Do you know about any alternatives to Portland Cement Concrete and asphalt materials used in sidewalk construction or other transportation infrastructure? For example, alternatives might include high performance concretes or permeable pavements.

2b. Please list these materials below:

2c. Has your organization specified the use of any of these materials?

2d. Please list these materials below:

2e. What may have motivated the organization's decision to specify or use the alternative sidewalk materials? Please check all that apply:

"For other environmental reasons (please fill in below)"

"For other reasons not listed above"

2f. In general, what has been the organization's experience with these materials?

2g. Do you have any specific examples you would like to share?

Question 3a. Do you know of any alternatives to traditional 4-inch poured Portland Cement Concrete in sidewalk designs and construction techniques? For example, alternatives might include incorporating green stormwater infrastructure, or printed voids in the design

3b. Please list these design or construction techniques below:

3c. Has your organization specified the use of any of these design or construction techniques?

3d. Please list these design or construction techniques below:

3e. What may have motivated the organization's decision to specify or use the alternative sidewalk designs or construction techniques?

"For other environmental reasons not listed (please enter below)"

"For other reasons not listed (please enter below)"

3f. In general, what has been the organization's experience with these designs or construction techniques?

3g. Do you have any specific examples of alternative sidewalk designs or construction techniques that you could share?

Question 4a. Does your organization identify heat mitigation as a goal or objective in the transportation planning process?

4b. Has the concern for heat ever influenced the design or materials used in projects that you have worked on or know about?

Question 5. Does your organization hear about heat concerns or receive heat complaints from the public?

Question 6. Describe your organization's level of concern about pedestrian heat exposure, extreme heat, and urban heat islands in the community in which you work.

Question 7. In what ways does your current role in the organization allow you or your team to mitigate the impacts of extreme heat and urban heat islands?

Question 8. About how many miles of sidewalk does your organization maintain?

Question 9a. Is there an official process used by the local or regional planning agency to prioritize the implementation of pedestrian infrastructure projects?

9b. In this project prioritization process, is there a scoring approach with weighting values that is employed?

9c. Is heat mitigation included in project prioritization decisions?

9d. Can you describe the factors including regulatory, economic, safety, and other decision-making criteria that determine project prioritization, material selection, and design for a given sidewalk project?

Question 10. Can you think of any particular parts of the decision-making process that either prevent or encourage the consideration and use of alternative sidewalk materials and designs?

Question 11a. Does the community you work in have an asset management system for pedestrian infrastructure?

11b. Does the community you work in have an inventory of sidewalks?

11c. Is the inventory of sidewalks and other pedestrian assets complete or partial?

11d. Does the community you work in have an inventory of ramps, curb cuts, crosswalks, or other pedestrian assets?

11e. Is the inventory of other pedestrian assets complete or partial?

11f. Is pedestrian asset condition tracked in the local agency inventory?

11g. What pedestrian asset design information is tracked in the local agency inventory?

11h. Is there a mechanism for the public to report pedestrian infrastructure problems?

11i. Do regular inspections of sidewalks or other pedestrian assets take place?

11j. How many years typically pass between inspections (please add any additional text detail about inspection frequency) and what data are collected during inspections?

Question 12a. To what degree are contractors used to perform asset management work, instead of being performed by local agency staff? [slider bar, 0 to 100]

12b. For what aspects of pedestrian asset management and planning activities are contractors used instead of being performed by local agency staff?

Question 13a. How are sidewalk projects funded? Is there a funding split between the town/city/county/state and the private property owners?

13b. How are other pedestrian infrastructure projects funded? Is there a split between the town/city/county/state and the private property owners?

Question 14. Are you aware of any issues surrounding pedestrian thermal comfort under extreme urban heat within your jurisdiction?

Question 15. On a scale of 1 to 5, how would you rate the severity of thermal discomfort for vulnerable pedestrian groups (e.g., elderly, wheelchair users, chronic disease patients) in your area?

Question 16. What actions or policies has your organization taken to date to improve thermal comfort for pedestrians during extreme heat events?

Question 17a. Are there specific projects or initiatives in your area that are aimed at protecting vulnerable pedestrian groups from the effects of urban heat?

17b. Please describe any projects or initiatives below:

Question 18. Do you have any other comments, suggestions, or concerns regarding pedestrian thermal comfort under extreme urban heat? Are there any other stakeholders or organizations you recommend we contact for further insights on this issue?

Question 19. Are there any strategies or approaches your organization is currently doing that involve green stormwater infrastructure or mitigating heat-related hazards that were not mentioned in this survey?

Question 20. Is there anything else you think is important to consider with sidewalk design, materials and maintenance that might be relevant to this survey?