

RESEARCH STATEMENT

Data collected by the World Bank [1] indicates that about a decade ago, the proportion of people in the world living in urban areas crossed those living in rural areas for the first time in modern history, and continues to rise steadily, with a majority of the increase coming from developing countries. This surge of humanity moving into urban areas has been the subject of studies in disciplines ranging from engineering to anthropology, all trying to understand how cities work and how they can be made to work better. In his seminal work, *A Theory of Good City Form*, Kevin Lynch [2] discussed the impact of urban form on its inhabitants, outlining five performance indicators on which to judge a good city: vitality, sense, fit, access, and control. His work has inspired researchers and planners to describe a city as a machine [3, 4, 5, 6] with specific properties and functions that can be optimized.

My research, inspired by Lynch, looks at a city as a machine with three interdependent parts: infrastructure, environment, and people. In my doctoral studies, I looked at the relationship between infrastructure (specifically, construction materials and pavements) and the local microclimate. As an independent researcher, I intend to grow beyond that by bringing together a variety of disciplines, such as mechanical engineering and computer science, under one lab to study each of these parts separately, as well as the relationship between them. As more people live in cities, my research will look to solve existing and emerging problems of heat islands, pollution, and resource scarcity, to make cities better places to live in.

PREVIOUS WORK

For my Master's thesis and doctoral dissertation, I investigated the relationship between urban infrastructure and the environment through a mixture of field and laboratory testing and computational modeling. I measured the thermal and optical properties of pavement materials, for which I developed a new technique to measure the reflectance of asphalt and concrete specimens in the field using an albedometer [7], backed by laboratory measurements using a spectrophotometer. I developed one of the first models on the aging behavior of asphalt reflectance [8] taking local conditions into account, and proposed a technique to calibrate the model easily at any location. I investigated the variation of the thermal and optical properties of asphalt and concrete specimens with a variety of mix designs using a rapid laboratory technique.

Using the thermal and optical properties, I investigated the impact of pavements on the local urban microclimate by using Computational Fluid Dynamics (CFD) to resolve the wind and temperature fields within a city block. To do that, I developed numerical models that resolve the temperature field inside a pavement [9] and coupled that to an urban canopy CFD model [10]. I demonstrated that, in addition to the thermal and optical properties of the pavement, the configuration of the urban form around the pavement, as well as environmental conditions on a larger scale, affect the canopy-level air temperature above the pavement. This, in turn, affects human health and comfort and is an important measure of the performance of a city. My research showed that there is an inherent relationship between infrastructure and the urban environment, and a unified approach to study the two is necessary.

FUTURE WORK

In my lab, I will further expand my research to comprehensively study the properties and performance of urban infrastructure, including pavements, walls, roofs, water bodies, and vegetation, and the relationships between them. Continuing from previous studies that used laboratory techniques or remote sensing to examine these [11, 12, 13, 14], my lab will study these surfaces in-situ at a small scale using Internet of Things (IoT)-based sensors mounted on the ground, cars, and drones. Here, I am inspired by the city of Baltimore’s Urban Heat Island sensor array. However, my lab will develop and deploy sensors with the aim of measuring meteorological variables around *specific* urban infrastructure (and not an entire city) to study its effect on the surrounding microclimate. Such a study is useful for engineers to plan individual projects with the aim of mitigating the impact on the surrounding environment.

Further, my lab will use field measurements to develop models of the urban environment using both computational and experimental approaches. Computationally, it is difficult to resolve turbulence in the wake of a building, and more so if other buildings are present in the wake itself. Most urban CFD researchers use Reynold’s Average Navier-Stokes (RANS) modeling with turbulence models that do not sufficiently resolve wake turbulence [15]. My lab will look to develop CFD codes that specifically address this issue using alternative but more-expensive methods such as Large Eddy Simulation (LES) and Direct Numerical Simulation (DNS), and then use machine learning to develop less-expensive turbulence models that work with a RANS approach for urban flows. We will make significant use of supercomputers for this. With these tools, we will investigate heat and pollutant distribution in cities during extreme events, such as congestion hours on roads and heat waves, and develop solutions for cities to better handle such events.

To study the urban environment experimentally, my lab will perform Wind Tunnel (WT) studies. For this, we will develop a wind tunnel that is capable of generating a stratified boundary layer flow and seeding it with particles. This WT can then be used to study flow behavior in a city during extreme events. A common challenge with urban WT testing is the difficulty in creating models that capture fine geometric features. To address this, my lab will look to use 3D printing for generating scaled models. A major aim will be to develop wind, heat, and pollution safety guidelines for designing urban infrastructure to mitigate their environmental impact. Wind tunnel experiments will also be used to fine-tune CFD modeling.

Ultimately, cities have to be designed for the people that inhabit them, and engineering designs must optimally use resources to benefit the largest number of people. My lab will look to identify how people in a city behave in response to urban infrastructure and environment, and delineate areas where the largest number of people are at risk to extreme environmental effects. We will do this using both traditional survey techniques as well as computational tools in social sciences. By locating areas that require improvements, we will use the insight gained from the lab to design solutions that fit each case best.

FUNDING AND STUDENTS

As my research area will cover a number of disciplines, several funding agencies are on my radar. I will apply to NASA's Research Opportunities in Space and Earth Sciences (ROSES) program, the Environmental Protection Agency's Health, Sustainability, and Air Research Grants, and the Department of Energy's Office of Science and ARPA-E for grants on studying urban infrastructure and environment. The National Science Foundation's Divisions of Chemical, Bioengineering, Environmental, and Transport Systems and Civil, Mechanical and Manufacturing Innovation, as well as their Critical Resilient Interdependent Infrastructure Systems and Processes (CRISP) and Big Data programs are other funding sources that I will be applying to. For behavior-related aspects of my research, I will apply to the Social Science Research Council's (SSRC) Abe Fellowship and the Russel Sage Foundation together with collaborators from the social sciences. For supercomputer resources, I will apply to the XSEDE network and Amazon Web Services (AWS) research grants.

Finally, I will apply for an NSF CAREER award. I believe that because of the multi-disciplinary nature of my research and its strong impact on urban societies, I will be quite competitive for the award. The award will give me the opportunity to advance urban studies as an inter-disciplinary area of study to provide solutions for the growing urban population around the world.

My long-term aim is to establish an inter-disciplinary Center for Urban Studies to institutionalize my research and attract other scholars to it. In my early career, I will interact with and advise students from several disciplines, specifically Mechanical Engineering, Civil Engineering, Urban Planning, and Computer Science. I will work towards obtaining the necessary departmental affiliations to do that. I will also collaborate with faculty and students from Electronics Engineering, Cultural Anthropology, Geography, and Atmospheric Sciences. I believe that by having students from such a wide variety of areas in one lab, they will have a unique and fulfilling research experience that will prepare them to meet the complex challenges of future cities. I would also welcome undergraduate students to contribute to my lab as valued members.

REFERENCES

- [1] The World Bank. Urban population (% of total) — data. <https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?end=2016&start=1960&view=chart>. (Accessed on Jan 24, 2018).
- [2] Kevin Lynch. *Good city form*. MIT Press, 1984.
- [3] Harvey Molotch. The city as a growth machine: Toward a political economy of place. *American journal of sociology*, 82(2):309–332, 1976.
- [4] Colin McFarlane. The city as a machine for learning. *Transactions of the Institute of British Geographers*, 36(3):360–376, 2011.
- [5] Richard Lloyd and Terry Nichols Clark. The city as an entertainment machine. In *Critical perspectives on urban redevelopment*, pages 357–378. Emerald Group Publishing Limited, 2001.

- [6] Tim R Oke. City size and the urban heat island. *Atmospheric Environment*, 7(8):769–779, 1973.
- [7] Sushobhan Sen and Jeffery Roesler. Albedo estimation of finite-sized concrete specimens. *ASTM Journal of Testing and Evaluation*, In Press.
- [8] Sushobhan Sen and Jeffery Roesler. Aging albedo model for asphalt pavement surfaces. *Journal of Cleaner Production*, 117:169–175, 2016.
- [9] Sushobhan Sen and Jeffery Roesler. Microscale heat island characterization of rigid pavements. *Transportation Research Record: Journal of the Transportation Research Board*, (2639):73–83, 2017.
- [10] Sushobhan Sen and Jeffery Roesler. An uncoupled pavement-urban canyon model for heat islands. In Hasan Ozer Al-Qadi, Imad L. and John Harvey, editors, *Pavement Life-Cycle Assessment: Proceedings of the Symposium on Life-Cycle Assessment of Pavements (Pavement LCA 2017)*, pages 111–120. CRC Press, 2017.
- [11] Paul Berdahl and Sarah E Bretz. Preliminary survey of the solar reflectance of cool roofing materials. *Energy and Buildings*, 25(2):149–158, 1997.
- [12] Aikaterini Niachou, Konstantinos Papakonstantinou, Mat Santamouris, Aris Tsangrassoulis, and G Mihalakakou. Analysis of the green roof thermal properties and investigation of its energy performance. *Energy and buildings*, 33(7):719–729, 2001.
- [13] Ranhao Sun and Liding Chen. How can urban water bodies be designed for climate adaptation? *Landscape and Urban Planning*, 105(1):27–33, 2012.
- [14] KP Gallo, AL McNab, Thomas R Karl, JF Brown, JJ Hood, and JD Tarpley. The use of a vegetation index for assessment of the urban heat island effect. *Remote Sensing*, 14(11):2223–2230, 1993.
- [15] Bert Blocken. Computational fluid dynamics for urban physics: Importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations. *Building and Environment*, 91:219–245, 2015.