

## **Areas of Existing and Emerging Excellence**

### **Smart and Sustainable Cities**

#### **Lead Researchers**

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for Social Good

## Executive summary

The world's urban population is expected to increase to 68% by 2050, up from 55% in 2018 [UN]. Closer home, Charlotte was the 7th fastest-growing large metro in the nation with a population growth of 15.9% between 2010 and 2018 [NCD]. The well-being of our society and the health of the planet critically depends on realizing a path to the sustainable development of cities so that the lives of residents are improved, the impact on the environment minimized, and cities made resilient to looming climatic challenges. Recognizing this need, in 2015, the Obama Administration launched a Smart Cities Initiative with \$160 million in investment through multiple federal agencies including NSF, DOE, DHS, among others. Key challenges identified include reducing traffic congestion, fighting crime, fostering economic growth, managing the effects of a changing climate, and improving the delivery of city services.

Our “Smart and Sustainable Cities” vision involves harnessing the recent technology advances of big data cloud computing, AI, Internet-of-Things (IoT), 5G communication, and low-cost sensors, to allow for fine-grained information processing to enable optimal decision making across a range of city services. Of particular note is the involvement of communities to develop community-led solutions to meet local needs while addressing privacy and safety concerns of the above-listed technologies. To address the associated research challenges, over the past few years, groups of researchers at UNC Charlotte have set up interdisciplinary research teams of faculty and students drawn from multiple departments, along with local community partners. These on-going projects have attracted significant external funding to the tune of \$8.7 million, resulted in 124 peer-reviewed publications, and involved 42 Ph.D. students over the last 6 years. The areas targeted by these transformative projects have focused on 5 major pillars: 1- Public Safety, 2- Public Transit Equity, 3- Sustainable Energy, 4- Accessible Health, 5- Resiliency of power distribution. Our broad objectives are - Mitigate socio-economic gaps, enable upward mobility for underserved communities, and chart a path of sustainable, environmentally friendly growth. We have assembled a multidisciplinary team, including AI engineers and technology inventors, experts in transportation, social science and public safety, and land use and city management, to bring recent advances in AI and data analytics to our communities to address complex challenges in public safety, health, transportation and our overall well-being.

We make the case that as an urban research university in a fast-growing city, with multiple on-going externally funded projects, and faculty with diverse expertise, UNC Charlotte is uniquely positioned to become a national leader in this fast-emerging field. We strongly believe that identifying “Smart and Sustainable Cities” as a core area of research and scholarship will draw more diverse researchers from across the campus and outside to this focus area. This in turn will enable the successful pursuit of higher impact larger external grants. Furthermore, the associated community involvement will promote greater integration and visibility of UNC Charlotte to the broader Charlotte area communities. Economic impacts include attraction of industry and startups to the Charlotte area, associated job creation, and positioning of Charlotte as a leading Smart City technology hub in the nation. Our aim is to create a “Smart City Research Ecosystem” to enable AI for social good. An ecosystem that offers a sustainable, scalable collaboration model between scientists, engineers, city officials, neighborhood leaders, city stakeholders, local business owners, and local students to make Charlotte a role model on “Community-Based Technology Inventor for Future”.

## **Evidence of Strength and Excellence**

Smart and Sustainable Cities (SSC) research at UNC Charlotte is broadly focused on both applied research to solve real-life urban problems in collaboration with community partners, and fundamental research on pushing state-of-the-art technology forward.

**Applied Research:** SSC related applied research focus areas currently include public safety, transportation, sustainable buildings, urban energy infrastructure, and public health monitoring. Among the key projects are -

- The \$2 million [NSF Smart and Connected Communities \(SCC\) project](#) led by Tabkhi (ECE) along with CJC, CEE, and CAGIS on building safe and secure communities through real-time edge video analytics. The project formalizes, and models public safety and security events to be machine detectable, reducing biases, and in enabling broad-based community support and trust. External partners include CMPD, CPCC, and City of Charlotte.
- The \$1.71 million I/UCRC NSF Center for Sustainable Integrated Buildings and Sites ([SIBS](#)) led by Cox (ECE) along with from faculty from SA for conducting research that promotes improved energy use, water use, air quality, and productivity in buildings through the integration of appropriate subsystems and technologies. External partners include BofA, Wells Fargo, Atrium Heath, Ingersoll Rand, and City of Charlotte.
- The \$0.94 million [DOE project](#) led by Cox (ECE) to develop innovative IoT enabled solutions for curbside charging of electric vehicles that can be retrofitted into existing street light infrastructure. External partners include Duke Energy and Eaton Corp.
- The \$0.5 million [NSF Cyber Physical System project](#) led by Tabkhi (ECE) along with faculty from ETCM on AI for highway worker safety. The project uses deep learning algorithms, edge computing, and assisted reality systems to enable real-time prediction of work zone intrusions and notification of highway workers.
- The \$1 million NCDOT Transportation Center of Excellence led by Pulugurtha (CEE) to advance transportation policies and safety incorporating advanced transportation technologies. External partners include UNC Chapel Hill, NC Central University, Appalachian State University, and NC A&T [[NCDOT](#)].

Other notable projects include research on contactless, non-intrusive, artificial intelligence (AI)-enabled contact tracing system for reducing the spread of viruses; development of Smart and Connected Buses in Charlotte for under-served communities along with faculty from ECE, PSPA, and SA; and DOE funded research on affordable, resilient, and sustainable power grid for North Carolina

The ongoing projects clearly break existing barriers by engaging faculties from diverse expertise from engineering disciplines, social science, and urban design and planning with non-profit organizations, and city stakeholders, working directly with community residents. We recently organized the first NSF funded [Smart City workshop](#) with a focus on Responsible AI for Society.

**Fundamental research:** SCC related fundamental research focus areas currently include new protocols, and algorithms for wireless communication in IoT and Edge, resource efficient machine vision algorithms, and novel use of UAVs as radio access points.

Among the key projects are -

- The \$632K NSF project led by Xie (ECE) on intelligent energy efficient spectrum access for wireless IoT that investigates developing the first of its kind integration of battery management systems, innovative wideband enhancement for electrically-small antennas, and energy-efficient channel rendezvous algorithms.

- The \$447K NSF project by Chen (ECE) and his collaborators for developing efficient deep learning networks for computer vision tasks such as object detection and recognition, human activity recognition, and anomaly detection. The project also develops novel wireless multi-hop federated learning systems that are stable, accurate and converge rapidly.
- The \$420K NSF project led by Han (ECE) on ubiquitous machine vision with adaptive wireless networking and Edge computing to design a platform that enables people from all over the world to share their smart camera.
- The \$333K NSF project led by Han (ECE) that aims to develop an innovative robust 3D airborne computing and networking system, that exploits a swarm of aerial mobile radio access points, and Edge servers carried or deployed by unmanned aerial vehicles (UAVs).

Other notable projects include the \$250K NSF project for distributed resource allocation at the Edge, \$360K NSF project on resilient and data driven management of grid edge devices, the \$300K NSF project to develop new algorithms for providing seamless mobility for Mobile Edge computing networks, and \$300K ONR project to enable real-time AI and Edge intelligence on IoT devices. Some of these projects are in collaboration with researchers from other universities, and industry.

**Publications and PhD students:** The research projects have resulted in 124 peer reviewed publications, and involved 42 Ph.D. students over the last 6 years. The products of the research have been integrated into related undergraduate and graduate curriculum at UNC Charlotte, and involved multiple activities to support K-12 outreach and diversity.

**Faculty expertise:** SSC draws upon the expertise of faculty in energy, urban design and planning, public policy, building design, transportation, criminal justice, machine learning, computer vision, cloud computing, wireless communication, hardware design, data analytics, and mathematical modeling. Of particular note is our success in forming fully operational, highly productive, multi-disciplinary teams with faculty drawn from across the campus, along with vigorous community involvement. The faculty serve on numerous external panels, have been recognized with best paper awards, and enjoy national media coverage [[POLITICO](#)].

**Future vision:** We believe that we are at the right juncture where injection of additional resources could make UNC Charlotte a national and international leader in this area. In particular, support for the university in establishing a Center for Smart and Sustainable Cities would pull the different research activities under a single umbrella, increase the breadth of activities, and be a go-to destination for communities, funding agencies, and industry to solve Smart City related challenges. We consider the Urban Collaboratory at the University of Michigan [[UMich](#)] as an inspiration for what we could accomplish at UNC Charlotte.

We also propose a “Smart City Testbed” within the UNCC campus or in a representative community neighborhood. The “Smart City Testbed” will be dedicated to showcasing and demonstrating the technology to the broader Charlotte community, partner agencies, and representatives from local government, to attract large federal fundings. The testbed serves as an exemplar to address many community challenges to make Charlotte a smarter city with economic and technology benefits for all. UNC Charlotte undergraduate/graduate students involved in Smart Cities research will directly use the space for technology development, as "Transition to the Practice" of theories and concepts developed at our research labs. As an example, Hamed Tabkhi and Shannon Reid are working with CPCC to build an “AI-Powered Privacy-Aware Public Safety” testbed at CPCC campus. A video demo provided here: <https://youtu.be/AgGg3rGSibE>

### **Alignment with Regional and National Priorities**

**National priorities:** In 2015, the Obama administration earmarked \$160 million for “Smart Cities” initiative with funds disbursed through multiple federal agencies such as NSF, DoE, DoT, DHS, EPA, and NIST. A Metrolab network of university-city partnerships was launched to leverage university expertise to address challenges facing cities and regions across the country, and promote inter-city collaborations [[METROLAB](#)]. The Metrolab network today has 30+ member universities, 30+ member cities, and 100+ projects. In North Carolina, only UNC Greensboro representing Guilford county is a member. With Charlotte being the largest city in the Carolinas, we strongly feel that UNC Charlotte should be a part of this national initiative.

The National Science Foundation has launched multiple programs targeting Smart Cities initiative including Smart and Connected Communities [[NSF-SCC](#)], Cyber Physical Systems [[NSF-CPS](#)], and Civic Innovation Challenge [[NSF-CIVIC](#)]. In 2020, DOE and USDOT issued \$5.25M in project grants to advance transit tech. DOE has multiple Smart City related programs including advanced grid modeling, and advanced distribution management systems. DHS has launched a Smart City Internet of Things Innovation (SCITI) Labs for public safety. A list of federal programs in Smart Cities is available [[NITRD](#)]

**International Priorities:** United Nations sustainable development goals emphasize inclusive, safe, and sustainable cities among the 17 goals for 2030 [[UN-SDG](#)]. A number of significant smart city initiatives exist in Europe [[EU](#)], South East Asia [[McKinsey](#)], India [[India](#)], Middle East [[MiddleEast](#)], China [[China](#)], Africa [[Deloitte](#)], and South America [[SouthAmerica](#)]. We believe that these represent significant opportunities for UNC Charlotte to build long term international collaborations, and an opportunity to raise the universities profile internationally. Projecting into the future, PricewaterhouseCoopers estimates the total value of the global smart city market projected to exceed \$2.5 trillion by 2025 [[PWC](#)].

**University Mission:** The research, educational, sustainability, outreach, and economic activities of the proposed “Smart and Sustainable Cities” research focus area aligns well with needs of the rapidly growing greater Charlotte region that the UNC Charlotte is committed to serve as a part of its mission. To explicitly build research capacity and foster collaboration, we will organize an annual workshop designed to generate and intellectually support a Smart City Research Ecosystem by bringing academics, local governments, activities and non-profit organizations, neighborhood leaders in the Charlotte region.

In conclusion, with continued rapid development in enabling technologies such as smart sensors, faster communication networks, and advanced algorithms leading to machine intelligence, the vision of Smart and Sustainable City would require active and close collaboration between engineers and social and behavioural sciences as well those in public services. This interdisciplinary collaboration is critical for the most effective realization of our vision of smart and sustainable cities as a means of enhancing the lives of global communities in an environmentally sustainable manner.

## Participating Faculty

ECE - Electrical and Computer Engineering

CEE - Civil and Environmental and Engineering

CJC - Criminal Justice and Criminology

PSPA - Political Science and Public Administration

SA - School of Architecture

ETCM - Engineering Technology and Construction Management

CAGIS - Center for Applied Geographic Information Science

Faculty	Title	Contribution/Expertise
Hamed Tabkhi	Asst. Prof., ECE	Real-time Privacy-Aware Artificial Intelligence, Cyber Physical Social Systems, Human-in-the-Loop Smart Systems
Robert Cox	Assoc. Prof., ECE	Monitoring and modeling for power conversion
Arun Ravindran	Assoc. Prof., ECE	System software for Cloud, Edge, and IoT
Jiang (Linda) Xie	Prof., ECE	Wireless communications and networking support for IoT, cyber physical systems, and connected vehicles
Tao Han	Asst. Prof., ECE	Machine learning for next-generation wireless networking and computing systems, Internet of Things (IoT), smart grid, and Blockchain systems
Chen Chen	Asst. Prof., ECE	Machine learning, Computer vision, Image and video processing
Srinivas Pulugurtha	Prof., CEE	Intelligent Transportation Systems, Traffic Safety
Badrul Chowdhury	Prof., ECE	Power system vulnerability and resiliency assessment, Integration of renewable and distributed energy resources in a smart grid, microgrid, and market environment
Sukumar Kamalasan	Prof., ECE	Modeling and Control of Energy Systems and Devices, Grid Resiliency, Operation and Management of Power Grid.
Shannon Reid	Assoc. Prof., CJC	Criminological Theory, Gangs, GIS Spatial Analysis, Intelligent Policing, Social Network Analysis

Douglas Shoemaker	Director, CAGIS	Human and Environmental systems, Sustainable Zero-Waste Systems
Omidreza Shoghli	Asst. Prof., ETCM	Intelligent Transportation Applications and Decision Optimization
Suzanne Leland	Prof., PSPA	State and Local Government Service Delivery, Public Transportation Equity
Mona Azarbayjani	Assoc. Prof., SA	Human-Centered Climate-Responsive Design
Nadia Anderson	Assoc. Prof., SA	Social Equity and Urbanism, Publicly-Engaged Design Practice