Smart Cities & Communities

January 2024—December 2024

Theme-end outcomes report for
Interdisciplinary research to address technical and social barriers in smart cities and communities

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Western Academy for Advanced Research

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~$440,000 CAD
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Cities that are forward thinking *and* people centred

Cities are changing. Extreme weather events, warmer temperatures, and population growth are piling pressure on public services and accelerating the deterioration of infrastructure.

Smart city technologies could revolutionize how cities approach urban planning and sustainability; however, these algorithmically driven solutions raise critical questions about surveillance, privacy, and social inclusion. With these concerns in mind, *Smart Cities and Communities* leverages the technical expertise of its members while also taking steps to ensure that their project, and others like it, will put the needs of the public first.

Theme members

Theme Leader & Western Fellow:
Ayan Sadhu (Engineering)
Western Fellows:
Abdallah Shami (Engineering), Anabel Quan-Haase (FIMS, Sociology)
Visiting Fellows:
Jalel Ben-Othman (Université Sorbonne Paris Nord), Katharine Willis (University of Plymouth
Post-Doctoral Scholars:
Liangfu Ge, Dimitrios Manias
Graduate Student Assistants:
Hillary Anderson (FIMS), Dereje Gultineh (FIMS), Takuya Maeda (FIMS)
Contributing researchers:
Mohamed Barbosh (Engineering), Premjeet Singh (Engineering)

***Interdisciplinary Approaches to Technical and Social Barriers in Smart Cities and Communities* envisions a future that is forward thinking, technologically advanced, and community minded.** During the theme's year-long tenure with the Western Academy for Advanced Research (WAFAR) (January 2024—December 2024), Theme Leader, and Canada Research Chair in Smart Cities and Communities, Ayan Sadhu (Civil and Environmental Engineering), Western Fellow Abdallah Shami (Electrical and Computing Engineering), and Western Fellow Anabel Quan-Haase (FIMS, Sociology), were offered the unique opportunity to forge a truly interdisciplinary path that bridges the gap between technological innovation and social responsibility.

With WAFAR's support, *Smart Cities and Communities* was bolstered by contributions from distinguished visitors Jalel Ben Othman (Université Paris Nord) and Katharine Willis (University of Plymouth), two WAFAR Postdoctoral Scholars with expertise in civil and computer engineering, and three WAFAR-funded graduate student researchers from the Faculty of Information and Media Studies. Drawing upon the strengths of this interdisciplinary dynamic, *Smart Cities and Communities* transformed breakthrough insights in sensing technologies, AI-driven systems, and digital ethics into a tool that could change the future of city management. Working in close partnership with the City of

London and campus partners (Facilities Management, Western Sustainability, Smart Cities and Communities Laboratory, and Optimized Computing and Communications Lab [OC2]), the theme developed a real-world “data-to-decision" solution that could lead to safer, more resilient infrastructure and greater sustainability.

WAFAR helped make these successes possible by challenging theme members to think beyond the familiar. Theme Leader Ayan Sadhu acknowledges WAFAR’s part in supporting *Smart Cities and Communities’* effort to build meaningful cross-disciplinary connections that will have a lasting impact on the project’s future:

Theme Leader Ayan Sadhu (Western Engineering)

“This has been a unique opportunity for us to brainstorm new interdisciplinary ideas for Smart Cities and Communities with Western researchers across faculties, top-notch visiting international researchers and their collaborators, and our industry and community partners. WAFAR has helped us prepare to establish a multidisciplinary team and develop strong foundational research of big ideas for future large collaborative grant applications.”

As of May 2025, the theme’s novel approach has helped them to secure over 400K in funding from external awards and additional internal support (in-kind) from Western Sustainability and Facilities Management. With this foundation in place, *Smart Cities and Communities* is prepared to advance technological solutions that will support the well-being of communities.

A people-centred approach to smart cities

Can smart cities create opportunities for community engagement? What harm could surveillance technologies cause and how might we mitigate it? How do we ensure that all communities and neighbourhoods benefit from smart city technologies?

Western Fellow Dr. Anabel Quan-Haase (Sociology, Faculty of Information and Media Studies) believes that the theme's continued focus on ethics and public engagement is what sets it apart from many other smart city initiatives.

"Too often projects like this only consider the ethics and the social implications in later stages of development or during implementation. An example of this type of approach was the **Sidewalk Toronto** project which ultimately was rejected by the community and city of Toronto because of the many social concerns associated with its implementation" says Quan-Haase.

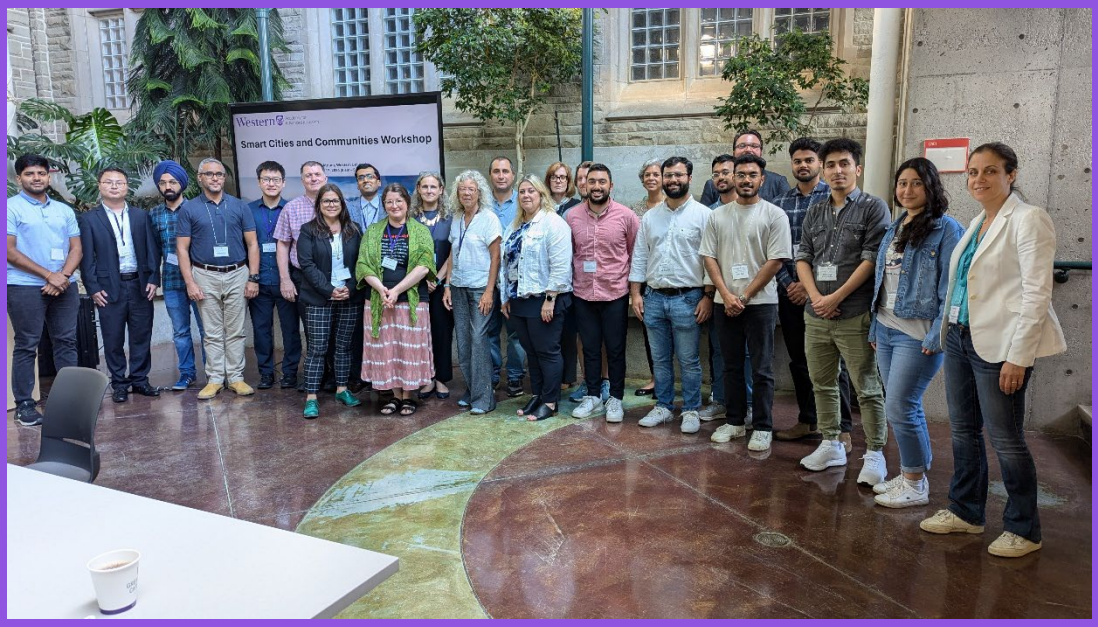
Questions about citizen privacy and ethical data collection are at the forefront of this project. Together with architect and Smart Cities and Communities Professor Katharine Willis (School of Art, Design and Architecture, University of Plymouth), theme members assessed how data-gathering technologies could benefit or harm the community. For example, Postdoctoral Scholar, and civil engineer, Liangfu Ge, worked closely with a Graduate Student Assistant from FIMS to assess the potential risks posed by automated vehicles. As the student explains,

International connections: Katharine Willis (University of Plymouth)

Visiting Fellow Katharine Willis advocates for a connected future where technology can foster social inclusion and citizen participation. A member of the International Telecommunication Union of the United Nations, Willis brings a rich understanding of digital technologies and how they shape our experience of urban spaces. Recently, Willis contributed insights to the UN policy document, Policy Benchmarks for Digital Transformation of People-Centred Cities (2024). Her ideas will be featured as part of the UN-Habitat Urban Lectures Series. As a Visiting Fellow with WAFAR, Willis was on site for a two-month long summer residency (July-August 2024).

> “We examined what types of information might be unintentionally captured.
>
> [We noticed that] cameras captured data such as license plates, and passengers on cars, and sidewalks, which could raise concerns about personal information. […] We also discussed questions, including: How many drivers are aware of automated vehicles in traffic? What types of concerns do people have regarding cameras in public transportation, such as buses? What kinds of collected data could potentially be misused?”

Visiting Fellow Katharine Willis (University of Plymouth) advanced the theme’s knowledge about AI ethics and monitoring technologies even further. A vital contributor to the *Smart Cities and Communities* team, Willis co-organized a symposium that brought together 75 participants from across the campus community and from the City of London. The *Smart Cities and Communities* symposium and workshop (July 17, 2024) showcased key developments from *Smart Cities and Communities*, featured talks from leading smart city thinkers from across Canada, and generated opportunities for discussion and feedback from stakeholders.



The Smart Cities and Communities Workshop connected leading thinkers in smart cities with researchers and stakeholders from across campus and the greater London community.

Key outcomes

A data-to-decision tool that could revolutionize urban management

Just as doctors check patients for signs of disease, engineers closely monitor structures for signs of damage and deterioration. Civil engineers refer to this as structural health monitoring. Using Western's campus as a "living lab," *Smart Cities and Communities* tested a novel application that measures and assesses road conditions and pollution levels on a street level.

Contributing researcher Premjeet Singh (left) and Postdoctoral Scholar Liangfu Ge (right) helped to design and implement a data-to-decision tool that was tested on Western's campus.

This cutting-edge tool consists of an AI-driven suite of cameras, LiDARs (light detection and ranging), and Internet of Things (IoT) sensors that can be attached to a city vehicle. The application is trained to record critical data about infrastructural damage (e.g., pavement cracks and potholes) and atmospheric conditions (e.g., temperature, humidity, and air quality) as the vehicle moves through the urban space. Theme Leader Ayan Sadhu explains the tool's potential to change the way that cities are managed:

> Our unique approach leverages the latest developments in mobile sensing, real-time data acquisition and automated visualization and decision-making about the critical infrastructure and environments of smart cities. When integrated with [city-owned] vehicles, this technology could radically shift how projects are managed, resulting in significant savings in the maintenance budget.

To transform their ideas into reality, *Smart Cities and Communities* worked closely with the City of London, Facilities Management, Sustainability Western, and the Smart Cities Laboratory (Western

Engineering). In Fall 2024 this emerging solution was tested on Western's campus, using a vehicle provided by Facilities Management, as part of Sustainability Western's *Campus as Living Lab* initiative.

Representatives from the City of London were involved in many stages of this project. On May 9, 2024, staff members from the city's Transportation and Climate Change department attended a brainstorming lunch, hosted by WAFAR, where they offered insights into how the model could enhance the city's approach to infrastructure planning, sustainability, and economic development. Theme members also met with interested representatives from the cities of Hamilton and Kitchener-Waterloo to explore the possibility of implementing this application in different municipalities across Ontario.

This initiative highlights *Smart Cities and Communities*' commitment to translating research into real-world solutions that will strengthen Western's presence in the larger community and beyond. In addition to funding secured from external awards and drawing upon secured funding from the Canada Research Chair program ($600,000 CAD),[1] the theme will seek additional major funding opportunities (New Frontiers in Research, NSERC CREATE, SSHRC Insight) that will help the project advance to its next stages (see *Future Directions*).

Smart Cities and Communities *met with members of the City of London's Transportation and Climate Department to discuss ways of translating their ideas into community solutions.*

[1] Theme Leader Ayan Sadhu secured a (Tier-2) Canada Research Chair in Smart and Sustainable Civil Infrastructure (2023-2028).

Improving bridge safety using robotics

A recent investigation has revealed that structural vulnerabilities may have played a key part in the catastrophic collapse of Baltimore's Francis Key Scott Bridge in March 2024. This tragedy highlights the necessity of structural monitoring and assessment, particularly in areas— like bridges and dams— that are very hard to access. *Smart Cities and Communities* has made inroads into new discoveries in intelligent design that could improve bridge safety and more.

This remotely operated robot was used by the theme to test new innovations in sensing and imaging.

Remotely operated robots (referred to as "unmanned ground robotic systems") can reach places that humans cannot. When equipped with sensing and imaging technologies, ground robotic systems can be used to generate clear visuals and 3D mappings of structures not otherwise visible to the eye. While highly promising, current systems can be costly, inefficient, and difficult to implement.

During their tenure at WAFAR, researchers from *Smart Cities and Communities* were afforded the dedicated time and support to develop a highly robust, streamlined system that could make sensing technologies more accessible and adaptable to different urban conditions. This critical new development has reached researchers and industry through a high impact journal (*Automation in Construction*, Impact Factor = 9.6). Throughout the course of the theme, members produced other novel discoveries in structural health monitoring, including contributions to research in underwater inspection, sonar technologies, automation, and deep learning.

Smart Cities and Communities in the news

Theme members Ayan Sadhu, Anabel Quan-Haase, and Katharine Willis have appeared in multiple outlets as expert voices in smart cities and social media technologies.

Katharine Willis was quoted in *The New Statesman* in a discussion about technology and social equity.

Ayan Sadhu was quoted in a *CTV News* article profiling the team's data-to-decision tool.

Anabel Quan-Haase discussed the TikTok ban, and the future of social media technologies, on CBC's *London Morning*.

Towards secure and reliable smart cities

Smart cities must be secure and adaptable.

Connected cities are especially vulnerable to hostile actors. While cyberattacks pose an obvious threat to public security, smart cities must be alert to other serious risks and challenges. For example, smart city systems are reliant on the most accurate and up-to-date datasets; however, volatile environmental conditions, like those caused by climate change, can render datasets obsolete, therefore seriously affecting how a smart city runs.

Smart Cities and Communities aims to address these challenges by developing cutting-edge, self-optimizing networks that rely on minimal human intervention. According to Western Fellow Abdallah Shami, a systems expert who also leads the Optimized Computing and Communications Research Laboratory (OC2), a self-adapting model is ideal because "adaptive systems demonstrate the capacity to learn continuously and update in real time, maintaining their accuracy and relevance in a world where climate change represents a significant and evolving challenge."

International connections:

Jalel Ben Othman (Université Sorbonne Paris Nord)

Visiting Fellow Jalel Ben-Othman (Université Sorbonne Paris Nord) is a leading researcher in mobility management and traffic forecasting in the urban environment. A noted expert on security in wireless networks, Ben-Othman consulted with *Smart Cities and Communities* about security and mobility management in connected urban environments, sensor networks, and Internet of Things (IoT). Ben Othman was on site at WAFAR for a combined total of 6 weeks.

Theme members seized the opportunity to use the *Campus as a Living Lab* project as a testing ground to finetune their approach to systems security and efficiency. The team mobilized their shared knowledge of autonomous vehicle systems, sensing technologies, systems security, and digital ethics to create an effective, responsive algorithm that proved critical to the data-to-decision tool's operations.

With support from external sources, such the Ontario Research Fund (~$210,000 CAD directed to Western), Shami and his team will continue this line of research by using connected and autonomous vehicle systems as a site for testing breakthrough solutions in security and efficiency. *Smart Cities and*

Communities hopes to use these results to develop solutions that can be applied to larger systems—including smart cities.

Making a case for AI literacy

A people-centred smart city is driven by informed leaders and engaged citizens. *Smart Cities and Communities* strives to create a framework for urban governance that prioritizes ethical leadership, citizen participation, and community engagement.

According to fellows Anabel Quan-Haase and Katharine Willis, meaningful citizen engagement is not possible without AI literacy. Broadly defined as "a set of competencies that enables individuals to critically evaluate AI technologies; communicate and collaborate effectively with AI; and use AI as a tool" (Long & Magerko, 2020), AI literacy empowers citizens and encourages responsible leadership. But even though AI is becoming increasingly integrated into our daily lives, findings from *Smart Cities & Communities* reveal that AI literacy is still an under-examined area of inquiry, particularly in Canadian research.

Funding from a SSHRC Knowledge Synthesis grant ($17,845 CAD directed to Western; joint UK-AHRC/ESRC submission) and a SSHRC Catalyst grant ($20,000 CAD) will support the theme's continued investigation into AI literacy. Support from the SSHRC Knowledge Synthesis grant will go towards producing reports and evidence briefs to support decision making and best practices in urban governance.

Western Fellow Anabel Quan-Haase led the project's inquiry into the broader social and ethical implications of smart city technologies

Future Directions

Smart Cities and Communities has laid the groundwork for exciting new developments that will bolster Western's reputation as a leader in smart city research. In the coming years, *Smart Cities and Communities* aspires to shape the future of smart city development by delivering break though technologies *and* a strong ethical framework that can be scalable to diverse communities. To attain this goal, *Smart Cities and Communities* aims to achieve the following outcomes in the coming year (2025):

- Scaling its data-to-decision tool to the City of London and beyond. This involves
    - Fine-tuning data-to-decision prototype with continued support from the Campus as Living Labs project (Western Sustainability), the Smart Cities and Communities Laboratory.
    - Building ties with the City of London and other municipalities in Southwestern Ontario.
    - Bolstering community involvement by building connections with organizations such as London Cross-Cultural Community Centre and London Public Library.

- Applying for major cross-disciplinary and cross-sectoral grants (NFRF, NSERC CREATE, SSHRC Insight).

- Advancing research into structural health monitoring of difficult-to-access infrastructure (*funding secured from NSERC Alliance grant*)

- Working in partnership with researchers from University of Ottawa and the University of Toronto to advance knowledge of cybersecurity in Automated Vehicle Systems (*funding secured from Ontario Research Fund*)

- Inform future policies and practices in AI Literacy (*funding secured from SSHRC Knowledge Synthesis and SSHRC Catalyst grants*)

- Generate public awareness about AI Literacy via educational videos (*MediaSmarts*)

Appendix A

External awards as of May 2025

Award	Title	PIs	Amount directed to Western	Dates of allocation
Ontario Research Fund-Research Excellence	Secure, Intelligent, and Trustworthy Ecosystems for Connected Autonomous Vehicles	Burak Kantarci (University of Ottawa), Abdallah Shami (Western), Xiabin Wang (Western), Birsen Donmez (University of Toronto)	~$210,000 CAD	2025-2029
NSERC Alliance Advantage	Towards structural control systems at the construction site in smart cities	Ayan Sadhu (Western)	$80,000 CAD	Sept. 2024-Aug. 2025
NSERC Alliance Advantage	Autonomous management of dam infrastructure	Ayan Sadhu (Western)	$60,000 CAD	Sept. 2024-Aug. 2025
SSHRC Knowledge Synthesis	New digital divides in the algorithmic city: Implications for urban governance	Anabel Quan-Haase (Western), Katharine Willis (University of Plymouth)	$18,000 CAD	2025
SSHRC Catalyst	Why AI literacy matters: a survey of Canadians	Anabel Quan-Haase (Western)	$20,000 CAD	May 2025-May 2027
Otto Moensted Fellowship		Ayan Sadhu	$50,000 CAD	Jan. 2024-Dec. 2025

Appendix B

Research Outputs

Publications (including preprint)

Aburakhia, S., Shami, A., & Karagiannidis, G. K. (2024). On the Intersection of Signal Processing and Machine Learning: A Use Case-Driven Analysis Approach. *arXiv*. https://10.48550/arXiv.2403.17181

Awadallah, O., Grolinger, K., & Sadhu, A. (2024). Remote collaborative framework for real-time structural condition assessment using Augmented Reality. *Advanced Engineering Informatics,* 62, 102652. https://doi.org/10.1016/J.AEI.2024.102652

Barbosh, M., Ge, L., & Sadhu, A. (2024). Automated crack identification in structures using acoustic waveforms and deep learning. *Journal of Infrastructure Preservation and Resilience, 5*(1), 10. https://doi.org/10.1186/s43065-024-00102-2

Carter, E., Sakr, M., & Sadhu, A. (2024). Augmented Reality-Based Real-Time Visualization for Structural Modal Identification. *Sensors, 24*(5), 1609. https://doi.org/10.3390/s24051609

Chouman, A., Manias, D., & Shami, A (2024). A Modular, End-to-End Next-Generation Network Testbed: Toward a Fully Automated Network Management Platform. *IEEE Transactions on Network and Service Management*, *21*(5), 5445-5463. https://doi.org/10.1109/TNSM.2024.3416031

Dehrouyeh, F., Yang, L., Ajaei, F. B., & Shami, A. (2024). On TinyML and Cybersecurity: Electric Vehicle Charging Infrastructure Use Case. *IEEE Access, 12,* 108703. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=10620263

El Rajab, M., Yang, L., & Shami, A. (2024). Zero-touch networks: Towards next-generation network automation. *Computer Networks*, 243, 110294. https://doi.org/10.1016/J.COMNET.2024.110294

Ge, L., & Sadhu, A. (2024). Domain adaptation for structural health monitoring via physics-informed and self-attention-enhanced generative adversarial learning. *Mechanical Systems and Signal Processing,* 211, 111236. https://doi.org/10.1016/J.YMSSP.2024.111236

Ge, L., & Sadhu, A. (2025). Deep learning-enhanced smart ground robotic system for automated structural damage inspection and mapping. *Automation in Construction,* 170, 1059951. https://doi.org/10.1016/j.autcon.2024.105951

Mittal, S., & Sadhu, A. (2024). Towards vision-based structural modal identification at low frame rate using blind source separation. *Journal of Infrastructure Intelligence and Resilience, 3*(3), 100085. https://doi.org/10.1016/J.IINTEL.2024.100085

Sakr, M., & Sadhu, A. (2024). Recent progress and future outlook of digital twins in structural health monitoring of civil infrastructure. *Smart Materials and Structures, 33*(3), 033001. https://doi.org/10.1088/1361-665X/ad2bd7

Shaer, I., Nikan, S., & Shami, A. (2024). Efficient Transformer-based Hyper-parameter Optimization for Resource-constrained IoT Environments. *IEEE Internet of Things Magazine*, *7*(6), 102-108. https://doi.org/ 10.1109/IOTM.001.2300285

Singh, P., Bana, D., & Sadhu, A. (2024). Improved bridge modal identification from vibration measurements using a hybrid empirical Fourier decomposition. *Journal of Sound and Vibration,* 590, 118598. https://doi.org/10.1016/J.JSV.2024.118598

Tamim, I., Shami, A., & Ong, L. (2024). ALAP: Availability- and Latency-Aware Protection for O-RAN: A Deep Q -Learning Approach. *IEEE Transactions on Network and Service Management, 21*(2), 2253–2265. https://doi.org/10.1109/TNSM.2023.3339302

Waldner, J. F., & Sadhu, A. (2024). A systematic literature review of unmanned underwater vehicle-based structural health monitoring technologies. *Journal of Infrastructure Intelligence and Resilience, 3*(4), 100112. https://doi.org/10.1016/J.IINTEL.2024.100112

Yang, L., Rajab, M. El, Shami, A., & Muhaidat, S. (2024). Enabling AutoML for Zero-Touch Network Security: Use-Case Driven Analysis. *IEEE Transactions on Network and Service Management, 21*(3), 3555–3582. https://doi.org/10.1109/TNSM.2024.3376631

Conference articles and presentations

Ge, L., & Sadhu, A. (2024, June 24—27). *Structural damage detection approach using input-ouput monitoring system and transfer learning* [Conference presentation]. IABMAS 2024, Copenhagen, Denmark.

Ge, L, & Sadhu, A. (2024, June 5—7). *Smart Ground Robotic System for Automated Structural Inspection and Mapping* [Conference presentation]. CSCE Structural Specialty Conference, Niagara, Canada.

Ge, L., & Sadhu, A. (2024, June 5—7). *Drone-based Smart Underwater Object Detection Approach for Structural Health Monitoring* [Conference presentation]. CSCE Structural Specialty Conference, Niagara, Canada.

Gemayel, A., Manias, D.M, & Shami, A. (2024). Machine Learning for Pre/Post Flight UAV Rotor Defect Detection Using Vibration Analysis. IEEE GlobeCom Conference. https://arxiv.org/abs/2404.15880

Manias, D. M., Chouman, A., & Shami, A. (2024). Towards intent-based network management: Large language models for intent extraction in 5g core networks. 2024 20th International Conference on the Design of Reliable Communication Networks (DRCN), 1-6. https://doi.org/10.1109/DRCN60692.2024.10539172

Manias, D. M., Chouman, A., & Shami, A. (2024). Semantic Routing for Enhanced Performance of LLM-Assisted Intent-Based 5G Core Network Management and Orchestration. IEEE GlobeCom Conference. https://arxiv.org/abs/2404.15869

Manias, D.M., Naoum-Sawaya, J., Javadtalab, & Shami, A. (2024). Probabilistic fault-tolerant robust traffic grooming in OTN-over-DWDM networks. 2024 20th International Conference on the Design of Reliable Communication Networks (DRCN), 76-83. https://doi.org/10.1109/DRCN60692.2024.10539142

Maeda, T., & Quan-Haase, A. (2024). When human-AI interactions become parasocial: Agency and anthropomorphism in affective design. *FAcct '24: Proceedings of the 2024 ACM Conference on Fairness, Accountability, and Transparency*, 1068-1077. https://doi.org/10.1145/3630106.3658956

Shaer, I., & Shami, A. (2024). Thwarting Cybersecurity Attacks with Explainable Concept Drift. *Proceedings of 20th International Wireless Communications & Mobile Computing Conference, May 2024*. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=10592411.

Tamim, I., Shami, A., & Refaey, A. (2024). Security and High-Availability while Upholding Network Defense Patterns: The Advantages of A2C in O-RAN VNF Placement. *IEEE International Conference on Communications*, *June 2024*, 1072-1077. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=10622252

Willis, K. (2024, Aug. 27—30). *Algorithms and urban AI: New digital divides?* [Conference presentation]. RGS-IBG Annual International Conference 2024, London, United Kingdom.

Willis, K, & Quan-Haase, A. (2024, June 19—22). *Algorithmic literacy in the smart city* [Conference presentation]. Canadian Sociological Association, Montreal, QC, Canada.

Workshops and seminars

January 2024

Katharine Willis delivered a guest lecture at WAFAR on AI ethics and bias.

May 2024

Abdallah Shami organized two panels at the Canadian Academy of Engineering conference that will be held in London, Ontario on May 27-29, 2024. https://www.cae-acg.ca/2024-conference/

Ayan Sadhu invited the City of London for a brainstorming session to showcase the latest progress of the theme for advancing urban-scale research on May 9, 2024.

June 2024

Ayan Sadhu was the Chair of the Structural Dynamics Committee of the Canadian Society of Civil Engineering (CSCE). He also served on the organization committee of the CSCE Conference to be held in Niagara in June 2024.

Jalel Ben Othman delivered a guest lecture at WAFAR on mobile sensing networks.

July 2024

Smart Cities and Communities organized a workshop on July 17, 2024, entitled "Smart Cities and Communities" at Western University, inviting various national and international researchers from North America and Europe.

September 2024

Dr. Sriram Narasimhan (University of California--Los Angeles) delivered a guest lecture at WAFAR on smart urban scanning and technology development in Los Angeles, USA.

November 2024

Katharine Willis was invited to deliver a lecture for the UN Habitat Global Lecture series 7 (only 6 selected globally), which was launched at the UN Habitat World Urban Forum in November 2024.

Willis served as a member of the panel of Plenary Keynote at the Royal Geographical Society Annual Conference, London 2024 on the theme of Digital twins, deep maps and the nature of mapping: Professor Rob Kitchin (Maynooth University, Republic of Ireland)