DR. DIMITRIS PAPANIKOLAOU

RESEARCH STATEMENT

My research integrates areas of big data, complex systems modeling, and interactive computing to design and analyze urban, building, and mobility systems of collective action. I focus on conditions that arise when multiple users share limited resources, and in how the design of space, connective technologies, and social mechanisms can induce cooperative behavior among users. I advance the fields of architecture, urban science, and computing, in three ways: 1) I develop data-driven simulation models that predict dynamics of urban systems; 2) I create enabling technologies that connect humans, objects and places across scales; and 3) I design mechanisms that induce cooperative behavior.

1. Data-driven Simulation Models that Predict Dynamics of Urban Systems

My first research area combines data with simulation models to predict dynamics of urban systems of collective action. I focus on mobility-on-demand (MoD) systems, like car, bike, and autonomous drone sharing systems. My models can be used by planners, researchers, and policy makers to address scenario analysis questions that would be too complex to address with conventional transportation modeling methods and too theoretical to address with machine learning methods. My dissertation, organized in three parts, showed that land use patterns and basic operational decisions, may define performance limits for MoD systems that no technology can overcome. In the first part, I quantified cost of shared mobility as the total rent (vehicles, parking land) and work (moving occupied and empty vehicles) required to mobilize a pattern of trips and I showed that rent and work requirements depend on the accumulation dynamics of locations. Then, I showed that any trip pattern can reduce to a simpler flow pattern between four clusters such that the accumulation dynamics of locations remain unchanged. The reduction allows modelling MoD systems with system dynamics methods, to address questions such as: How does a pattern of trips affect cost and utilization across cities? In the second part, using Boston's bike sharing system as a case, I developed a data-driven system dynamics model that models how sizing and rebalancing decisions affect cost and utilization of shared mobility. The model uses a trips dataset as input and allows a user to interactively explore scenarios such as: How would vehicle and parking rent requirements change for a marginal change in rebalancing work? In the third part, I developed a Land Use Transport Interaction (LUTI) dynamic macromodel that links land use distribution to cost and utilization of shared mobility. The LUTI model creates a land use pattern from eight parameters, generates daily flows from the land use pattern, computes the resulting regional accumulation dynamics, and allows a user to interactively explore questions such as: how do land use patterns affect rent and work requirements? My dissertation concluded with three findings: increasing land use segregation, or increasing commuting over leisure trip purposes, decreases utilization; increasing rebalancing work decreases rent requirements but increases traffic with empty trips; based on the relative costs of land and technology, there might be cities in which, shared mobility can never be more affordable than private mobility. My current research expands this area in several ways. In a recent project, we used data from taxi cab systems to assess the potential of autonomous MoD systems. In another project, we use Machine Learning to identify how much time taxis spend travelling empty versus parked while in another project we comparatively analyze trip data from both dockless and docked bike sharing systems, to understand when one is better than the other. Finally, in another ongoing project, we generalize reducibility of MoD systems, showing that any pattern of trips generated by known global activities, can reduce to a simpler flow pattern such that the cost requirements before and after reduction remain practically unchanged. The long-term goal of this research area is to develop design tools to reciprocally relate urban form to dynamics and cost of MoD systems: on one hand, to predict dynamics by analyzing urban forms; and on the other hand, to infer urban forms and land uses by analyzing dynamics. Formalizing this reciprocal relationship is important not only for understanding the potential of on-demand mobility in current cities but also for planning future cities that meet desired performance metrics for implementing MoD systems.

2. Technologies that Connect People, Objects, and Places

My second research area creates technologies that connect people, objects, and places across scales, physically or virtually. This includes tangible telepresence interfaces, multiuser participation platforms, and computable materials. The following projects illustrate examples of this research area. *BodyPods*, inquired the potential of the built environment to mediate human telepresence at an interpersonal level, posing the question: *how might manifesting traces of our activities reveal more about ourselves?* I created a pair of multi-sensory seats that allow a person on one seat to perceive the presence of the remote person by sharing their bodyprints through the internet. Analogous to a fingerprint, a bodyprint manifests a person's sitting posture as a distribution of their body pressure on the seat. *BlockNet,* investigated the potential of physical structures to mediate information, using their parts and their assembly interconnections as a local internet. I designed and prototyped a set of addressable building blocks that communicate through physical contact, and I explored how they may guide a user to assemble them in preprogrammed configurations. Currently, in *Pneuxels*, I develop a software/hardware platform that allows humans, objects and places to connect, similarly to how a chat application allows multiple online participants to converse. Pneuxels (Pneumatic Pixels) are pneumatically actuated programmable pixels that change their physical state based on input from other Pneuxels, from the environment, or from users.

3. Mechanisms that Induce Cooperative Behavior

My third research area investigates mechanisms for collective action and how simple option policies in combination with self-interest can create equilibrium conditions for self-organization. In my MSc thesis *The Market Economy of Trips* (MET), I asked the question: *Can self-interested users collectively govern MoD systems?* I designed and analyzed a pricing mechanism to incentivize users to rebalance the fleet, causing some trips to cost more while others to pay back. The problem of pricing concentrates on maximizing ridership in a socially equitable manner while guaranteeing that revenues from penalties pay costs for rewards. Pricing trips is hard since: a) the set of all possible prices for all possible trips grows exponentially with number of stations; b) trips are intangible assets, neither in shortage nor in abundance; and c) determining socially fair prices through a central self-interested entity is unfeasible. To address this problem, I designed a two-sided market in which users “buy” vehicles from origin stations and “sell” them back to destination stations, essentially translating the intractable problem of pricing trips to the tractable problem of pricing inventories. Trip values derive as transactional differences between buying and selling and can be positive, negative, or zero. Price competition between “station dealers” brings the system in equilibrium by relocating wealth from users willing to pay to save time to users willing to profit from spare time. By analyzing the equilibrium, I showed that the surplus wealth from high to low payers equals the cost of the substitute plus the time value difference in users. In theory, this guarantees a Pareto optimal equilibrium. Two more projects complement this research. *PriceScapes,* focused on how information visualization might communicate spatiotemporal payoff information to users of incentive-driven MoD systems. Working with data from bike-sharing systems, I developed a visual interface for handheld devices that associated pick-up/drop-off prices at stations to color-gradients on a map. Relocating vehicles from lighter to darker tones is rewarding while the opposite is penalizing. In *Cloudcommuting*, we develop a full-stack cloud-based electronic marketplace for dynamically pricing trips in MoD systems built in technologies like socket.io, node.js, and mongoDB. The platform allows two types of user accounts, riders and traders, to register online and transact over physical locations in real time. An urban scale game experiment is currently under planning.

Future of Urban Synergetics

In conclusion, my research aims to develop a comprehensive approach to the design and study of cybersocial urban systems of collective action, based on systems modeling, data, physical computing, and creative practice. In the next 5 years I want to expand my research to a number of open questions: *How might we develop design tools to plan urban cyber social systems with predictable behavior? Under what circumstances can autonomous technologies improve self-organization in cyber social systems? In what ways might the integration of social mechanisms and design induce self-organization in cyber social systems?* I plan to address such questions through large-scale experiments using urban districts as live testbeds. I hope that, learning outcomes from such research may change profoundly how people live, move, and share, in 21st century cities.

5. Related Publications

D. Papanikolaou, A. J. B. Brush, and A. Roseway, “BodyPods: Designing Posture Sensing Chairs for Capturing and Sharing Implicit Interactions,” in Proceedings of ACM SIGCHI TEI’15: 9th International Conference on Tangible, Embedded, and Embodied Interaction, Stanford, CA, USA, 2015, pp. 375–382.

D. Papanikolaou, “Choreographies of Information: The Architectural Internet of the Eighteenth Century’s Optical Telegraphy,” in New Geographies, vol. 7, A. Fard and T. Meshkani, Eds. Cambridge, MA: Harvard Graduate School of Design Press, 2015, pp. 45–55.

D. Papanikolaou, “Cloudcommuting: Games, Interaction, and Learning,” in Proceedings of the 12th International Conference on Interaction Design and Children, New York, NY, USA, 2013, pp. 459–462.

D. Papanikolaou, “Computing (with) Architecture: Pedagogical Explorations at the Intersection of Design and Mechanical Computation,” in BLACK BOX: Articulating Architecture’s Core in the Post-Digital Era, Pittsburgh, PA, 2019.

D. Papanikolaou, “Computing and Visualizing Taxi Cab Dynamics as Proxies for Autonomous Mobility on Demand Systems | SpringerLink,” in Computer-Aided Architectural Design. “Hello, Culture,” vol. 1028, Daejeon, Republic of Korea: Springer Singapore, 2019, pp. 183–197.

D. Papanikolaou and K. Larson, “Constructing Intelligence in Point-to-Point Mobility Systems,” in 2013 9th International Conference on Intelligent Environments, 2013, pp. 51–56.

D. Papanikolaou, “Data-driven State Space Reconstruction of Mobility on Demand Systems for Sizing-Rebalancing Analysis,” in Proceedings of the 2018 Symposium on Simulation for Architecture and Urban Design (SimAUD 2018), Technical University of Delft, Netherlands, 2018.

M. Deshpande, S. Sarwar, A. Mahdavi, and **D. Papanikolaou**, “Pneuxels: A Platform for Physically Manifesting Object-Based Crowd Interactions in Large Scales,” in Proceedings of the 2019 ACM International Joint Conference and 2019 International Symposium on Pervasive and Ubiquitous Computing and Wearable Computers, London, UK, 2019, pp. 9–12.

Papanikolaou,Dimitris, “The Potential of On-demand Urban Mobility: Lessons from System Analysis and Data Visualization,” Doctoral Dissertation, Harvard University, Cambridge, MA, 2016.