The Manual of Networked Possibilities: A Collection of Forward-Thinking Interventions for Intelligent Cities

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INTRODUCTION

In 2012, the city of San Francisco commissioned Paradox Engineering to deploy a pilot industrial wireless network to manage urban infrastructure, effectively creating an "Internet of Things" (IoT) at the urban scale. That convergence of high-speed wireless networks, locative technologies, and environmental sensor systems is prompting a reconceptualization of the city, one where physical space is no longer understood as independent from digital space. The two spheres, physical and digital, are becoming increasingly intertwined.

When communication media went through technological change in the past, each transition eventually led to social and cultural change that was unforeseen.[1] Just as the agricultural and industrial revolutions transformed the way cities were imagined and configured, networked technologies also have the potential to reconfigure our urban practices and formations.[2] Thus *Intelligent Cities* is emerging as an important research area, drawing together architects and designers to explore opportunities at the intersection of computer science, industrial design, and urban studies. The challenge remains, however, in balancing a humanistic design approach with quantifiable gains in environmental and infrastructural control. As a means to critically explore the possibilities of such a networked infrastructure, this paper discusses research projects from *Intelligent Cities*, a graduate level seminar at the University of Illinois Urbana Champaign.

These projects integrate principles of context-aware systems (e.g., computer systems that provide relevant information and services to users by exploiting context). For architects, context means information about a location, its environmental attributes (noise level, light intensity, temperature, motion, or other information) and the people, devices, objects and software agents it contains. Context may also include system capabilities, services offered and sought, the activities and tasks in which people and computing entities are engaged, their situational practices, and intentions.

If context is key, then *Intelligent Cities* advances three important goals: The first is to critically examine a set of assumptions about technology in relation to the city, already embedded within the discipline of urban design. While networked urbanism is enabled by technologies, it is produced through social interaction.[3] Drawing on contemporary urban scholarship along with everyday social practices—for example, what it is actually like to move through and live in contemporary cities—brings a multitude of experiences coexisting within even the same urban space. This heterogeneity is central to our approach.[4] Second, studying types of user experiences favored by this research paradigm entails an ethnographic methodology.[5] By means of surveys and questionnaires, the collected user-data contributed to project analysis and design.

Understanding the relevant and available technology and speculating on its future development is a critical first step in theoretically repositioning an argument for networked urbanism. Drawing from recent research, the paper discusses *Street Smart*, an urban mobility strategy with four applications: (1) human/autonomous vehicle logistics; (2) road safety; (3) traffic optimization; (4) parking optimization. I will discuss the overall system organization before describing each application. The findings serve as a springboard definition for networked infrastructural optimization strategies. This consolidated proposal demonstrates realizable applications of the research, as well as a speculative testing ground for further analysis, discussion, and future implementation.

STREET SMART

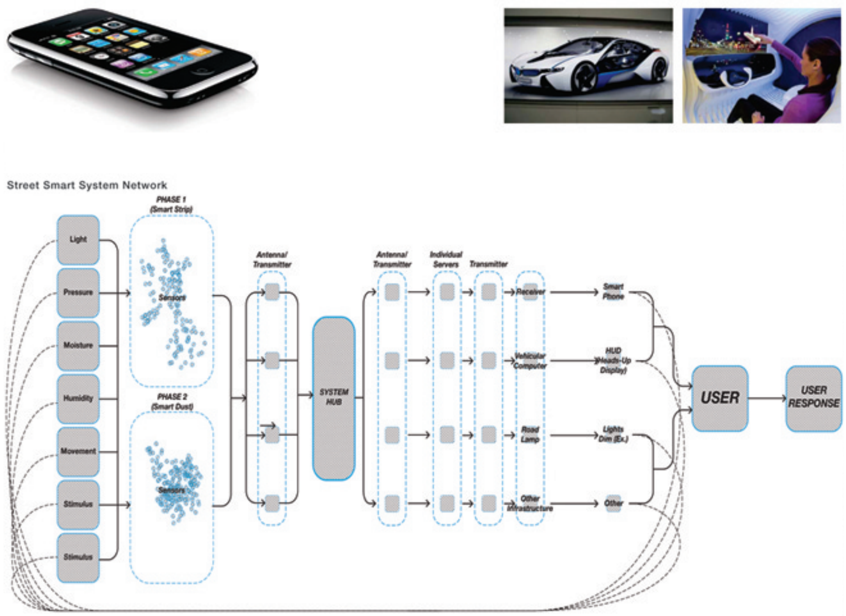
What are the possibilities for coordinating people, vehicles, and context? Can automated surveillance mechanisms be employed as system monitors, and can the information be usefully translated into an optimization strategy? The efficiency of transportation infrastructure is inherently impacted by the scale of the system, and it is practically impossible to monitor its entirety at the human scale. This disassociation of scales in both time and space are barriers against optimizing this infrastructure for maximum utility. Parking garages, for example, are inevitably inefficient because monitoring the entire system for open parking spaces is at best challenging, and predicting the time each space will be occupied is impossible.[6] Lighting systems for rural interstates waste millions of kilowatt-hours per year illuminating deserted roads.[7] Thus the development of new canvassing mechanisms (Smart Dust, for example), and the rise of networked devices (in particular mobile smartphones) reintroduce the discussion of relevant applications. This discussion investigates the potential for networked technologies to address traditionally explicit yet difficult to manage systematic characteristics.

BACKGROUND

The positive effects of sustainable transportation practices are well documented. It has also been established that the personal automobile is inefficient in its manufacture, marketing, and utilization. *Street Smart* is a networked sensing and actuating system designed to optimize and enhance navigation-reliant activities. It builds on and extends earlier work at the *URL: Urban Research Lab* with regards to sustainable mobility systems, specifically ridesharing and route management for autonomous vehicles. In *Reinventing the Automobile*, the late William Mitchell sets out four ways in which personal transportation will likely adapt to fuel scarcity: (1) an underlying design system based on electric-drive and wireless communications; (2) a Mobility Internet for sharing traffic and travel data; (3) smart electric grids based on renewable energy; (4) dynamically priced markets for electricity, road space, parking space, and shared-use vehicles.[8] Those four future systems describe some of the ways in which intelligent infrastructure will impact the urban experience. All could be considered *adaptive systems* (e.g., wireless mobile communication devices as a means to organize people and vehicles through sensors). As part of an ongoing reconfiguring of urban transportation, autonomous automobiles integrate three components: (1) mobile communication device which is (2) overlaid with a social software application operating in real time and (3) an autonomous vehicle.[9]

Other research completed by electrical engineer Don McLean in "Adaptive Roadways," notes roadway lighting accounts for approximately 30% of the average municipal energy consumption in North America. The study investigated an adaptive lighting product, *Streetlight Intelligence Lumen IQ*. The system uses a sophisticated network to control dimmable lamps, whose luminosity is adjusted per location based on the time and weather. The systemic benefits involve considerable reduction in energy usage, accurate power usage measurement, improved maintenance efficiency, electrical component protection for cycling luminaries, and increased monitoring of equipment performance. Mclean's findings suggest that adaptive roadway lighting systems with lumen output set to 50% can reduce energy consumption by 40%. Nonetheless, the system lacks specificity. While the time of day and weather data can be averaged for performance behavior, the conditions do not change at the level of the individual vehicle. Unlike simple adaptive lighting systems, smart technologies can draw information from mobile phones and networked vehicles and mediate this information against that which is already programmed in the system. If implemented, smart technologies can further reduce energy consumption and provide optimal lighting conditions for a vehicle at a specific point in time.

A precedent for parking optimization was also reviewed. Transportation engineer Todd Litman calls for contingency-based planning in "Parking Management: Strategies, Evaluation and Planning." Litman's strategy requires an initial observation phase, and then applies various situation-specific parameters of the parking facilities to better accommodate the actual use of the facility. What Litman did not explore, however, is the possibility for networked surveillance devices in conjunction with smart technologies



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to harness this information to report statistical data, and more importantly, user-specific direction to enhance the capacity of the system. The implementation of smart technologies can further optimize parking systems by evaluating the performance of the parking facility, as well as various infrastructural parameters (number of parking spaces), which can be reduced by a determined percentage. Ever-changing parameters (cost of parking, determination of peak times, and so on) can recalibrate constantly based on the condition of the entire system at literally every point in time.

SYSTEM COMPONENTS

Street Smart relies on Smart Dust technology under development by Kris Pister at the University of California, Berkeley. Smart Dust particles are planned to be no more than 1 cubic millimeter in size, which includes a solar cell, a sensor, a central processing unit, memory, and a radio transmitter. A radio frequency identification tag is an electronic identification device that is made up of a chip and an antenna. Global positioning system is an electronic system that uses a network of global satellites to determine the position of an entity, for example, a vehicle, person, or transfer point. The goal of the project is to develop inexpensive self-contained electronic devices that have computational ability, with built-in sensing and powering capability. The devices can network wirelessly with one another and may be deployed on a grand scale (hundreds or more). These devices are referred to as 'motes.'[10] Functions of the device may include but are not limited to light detection, motion/vibration detection, temperature and humidity readings, air pressure, and more. 'Motes' are run by microcontrollers that determine the function of a 'mote.'[11]

Figure 1: An intelligent sensor contains some or all the processing needed to convert sensor data to meaningful information. This information is then relayed to a system hub where it is transmitted to users.

Smart Dust technology can be infused into surface materials transforming the ground into a networked sensible canvas, able to detect movement, pressure, temperature, and humidity. Conceptualizing the street as a networked sensing device broadens the capacity for surfaces to relay intelligent information to users. Severe environmental factors can be mitigated by surface-enhancing actuated response. Limited-capacity systems can be optimized and users directed into and out of the system fluidly. The advantages to developing a low-cost, low-impact smart-surface-enabling technology are varied and its applications—virtually limitless—share a common goal to organize, facilitate, and optimize transportation activity.

Street Smart is the sensing component of a large network-based apparatus. Ambient information is collected by the hardware-infused surfaces, and is relayed to a central cloud network that evaluates the input and determines based on the coding of the specific applications particular outputs. Depending on the context, the system may summon interaction from network-integrated smartphones, alert emergency personnel, and other networked and autonomous vehicles, and so on. The system may also have automated system-enhancing responses, wherein the system detects and autocorrects a situation independent of human input (Figure 1).

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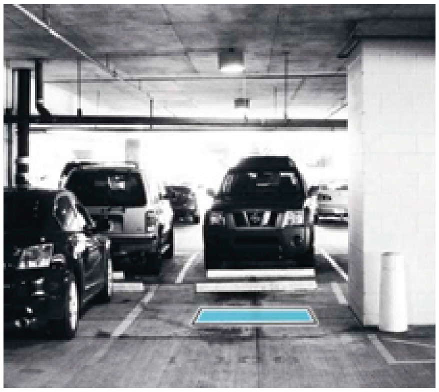

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ROAD SAFETY STRATEGIES

Road safety pertains to optimizing or mitigating the conditions of environmentally affected surfaces. For example, *Street Smart* can detect if snow or ice is covering paint markers on the road, and respond by heating up slightly to melt away the obstruction (Figure 2). If the system detects conditions poor for visibility, or potentially dangerous levels of snowfall, the system can respond by emitting light to illuminate paths and markers in the road for enhanced clarity.

The road safety application requires a sensing device (in this case, the smart-dust infused roadbed), a method of controlling the lighting infrastructure (a networked program mediating the information gathered from the road and an actuating mechanism for changing the light level), and an input source (traffic and weather). First the smart dust detects the presence of a vehicle. This information is instantly interpreted and evaluated against the current light levels near the vehicle's location. Low light levels activate the street lamps in the vicinity to an appropriate level. Controlling the light levels improves the energy efficiency of the system by providing the optimum amount of light only when needed. Simultaneously, the Smart Dust is analyzing the interaction between the street and the car and comparing this performance with weather data harvested from the national weather survey. The Smart Dust determines the optimum performance characteristics of the pavement and attempts to mediate the natural surface condition with the vehicle's performance statistics (which the vehicle individually relays to the system). On a small-scale application (for example lane markers) the Smart Dust can heat itself and melt to improve the visibility of the marker. On a larger scale the behavior of the road surface can be both performance enhancing (melting ice and snow) and informative (reporting event data, for example, accidents, or visually communicating data to drivers).

Figure 2: Road network road sensors

Figure 3: Networked parking

TRAFFIC OPTIMIZATION

The monitoring capacity and networked dialogue between the main system (road, signals, and cloud network), and the individual system (typically a vehicle) can modify or direct traffic in real time based on event-driven data gathered from the city. The system presents information either to the vehicle itself (through the vehicle's onboard navigation system), or through a smartphone application such as Google Maps. A person programs a route into his or her phone or car. If an accident or road conditions make the route impassable, the monitoring infrastructure communicates this information through the route trajectory, which updates immediately. The response can be as passive as simply redirecting an individual vehicle, or more direct. For example the system can pause traffic by changing or modifying the length of traffic signals, and can communicate route closures instantly on continuously updated highway marquees. On a broader scale the system monitors traffic flows and subtly adjusts traffic signals in real time to alleviate congestion and reduce stopped traffic. In the future, the same system can organize riders and vehicles.[12]

PARKING OPTIMIZATION

The final application, *Park Smart,* addresses the inherent inefficient characteristics of parking structure organization. The system senses a vehicle entering the garage and assigns a tag to track the car and its position in relation to the vehicle queue. The system then references a database of available spaces in the garage, while continuously monitoring and evaluating occupied spaces and ranking them according to vacancy probability. The system delivers instructions directly to the entering vehicle to proceed directly to a pre-assigned open spot in the garage. The system can respond in real time, reserving the capability to link location-based technologies (i.e., mobile phones) belonging to people who have parked to determine, for example, if a person is headed back to a car to leave the garage. The system will then route a car to fill the spot (Figure 3). The system can be augmented to interface with phone applications to remind users of the location of their vehicles.

Park Smart furthermore features an "in-between parking" strategy to leverage space between parked automobiles where passengers exit from only one side of the vehicle. When the system engages the vehicle the user is asked to indicate whether one or both side passenger doors will be opened. If one side is indicated, the system directs the car in a specific direction to a particular space. When a bicyclist or motorcyclist enters the garage the systems engages the vehicle differently and directs them to a "mini spot" between two parked cars. The capacity of the park system is increased at no additional infrastructural cost.

Street Smart, and indeed, the concept of the smart city have far reaching capacity to dramatically improve the organization of experience and utility of the built environment. The omnidirectional sensing capacity of the system dismantles the barriers of scale that traditionally preclude the degree of specific city requisite of automatic parking and traffic optimization strategies. The system is made possible by emergent smart technologies such as Smart Dust, cloud networks, smart mobile devices, and the Internet, and implements public-sector infrastructural changes as minimally as possible. The total cost and production associated with implementing the system is naturally reduced, increasing the viability and propriety of its realization.

Street Smart is not a new strategy, but rather combines and expands components of precedent projects in a new way. In many ways the system invokes a diagrammatic framework for future expansion because of its programmable nature; in other words, the applications can grow and new ones instituted based on the type of information and the way the system interprets this data. Given this open-ended infrastructure the opportunities for future development are significant. Our next phase of research is to realize the expanded functional capacity of the system by identifying particular relationships between information and performance. For example, in what additional ways can the traffic management algorithm refine itself over time? Does the system learn to predict certain traffic patterns at specific times on specific days in conjunction with weather phenomena? How does the system behave in the absence of stimuli, or when the vehicle is not equipped for interaction? In other words, this framework is flexible, feasible, and situated for open-ended development.

CONCLUSION

The dialogue implicit in the *Intelligent Cities* seminar extends far beyond project realization. The impact of networked media is revealing—by circumstance or otherwise—new relationships in the organization of the built environment. The value of any system lies not only in the improved functionality and optimized performance of existing infrastructure, but also in the exposure of camouflaged discourses and the realization of augmented potentialities.

Thus the social consequences of coordinating actions and locations in space, vis-à-vis networked technologies, have not been fully calculated. As an invisible matrix of connection, individuals, as well as other entities, can be geospatially located at all times, raising serious questions about privacy. Theorist Barry Katz cautions that designers should not only concentrate on problem solving, but also on the social, political, and environmental consequences of their design decisions.[13] While the focus of this project is not on infrastructure per se, a human-centered design approach to networked infrastructure compels not only architects and urban designers, but also public policy makers and everyday citizens to actively participate in the planning process, foreseeing future challenges as well as opportunities. ◆

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