Data-Driven Design Process for Human Interaction, Urban Metabolism, Health and Well-Being, and Urban Ecotones in Smart Cities

This paper addresses the architecture of urban development and smart city planning. The techniques described here are grounded in a data-driven design approach that gathers and analyzes information from a city and its inhabitants, leading to creative and efficient user-centric designs.

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ABSTRACT

This paper addresses the architecture of urban development and smart city planning. The techniques described here are grounded in a data-driven design approach that gathers and analyzes information from a city and its inhabitants, leading to creative and efficient user-centric designs. While research related to smart cities is becoming increasingly abundant, research on the data-driven design approach to smart city architecture is still in its infancy. The core question of this research is how designers can influence the paradigm of smart cities by putting an emphasis on data-driven design processes. Spokane, Washington's Smart City Accelerator Group, which includes Washington State University's School of Design + Construction, is researching how to incorporate smart city technologies in Spokane's University District. Through the Integrated Design Research (IDR) Studios at WSU, researchers are experimenting with different methods across multiple disciplines to determine what mechanisms can be used to best create cities that monitor, analyze, and utilize data to improve infrastructure, security, and social and economic services for their inhabitants. Students in the fields of architecture, interior design, and landscape architecture are incorporating research-based, data-driven design solutions to confront current and future needs that can be addressed through the built environment. Researchers at IDR Studios evaluate smart cities through four main categories: Human Interaction, Urban Metabolism, Health and Well-Being, and Urban Ecotones. By examining Human Interaction with natural, technological, social, and built environments, researchers aim to create a city whose infrastructure, services, and systems cater specifically to the individuals living in that particular location. A city's Urban Metabolism is the interaction of resources, materials, and people that researchers hope to shape into more efficiently functioning system. Technologies may also be utilized to improve Health and Well-Being in a city, by providing opportunities and services that more effectively respond to and influence people's behaviors. Finally, Urban Ecotones are areas in the city that are separated by existing conditions—either physical or social. Researchers are investigating ways in which these dividing lines can be blurred or bypassed to enhance the culture, health, and inclusivity of the city. By data mapping the Spokane University District's existing conditions and health indicators, researchers at IDR Studios are using solid empirical

data to develop design solutions that will improve the area's welfare, social health, and community engagement. It is anticipated that this work can help to create a paradigm shift in the mindsets of the city's inhabitants, bringing the city of Spokane closer to achieving its goal of becoming a technologically advanced, human-centric smart city.

Keywords: Data-Driven; Design Process; Design Computation; Human Interaction; Metabolism; Health and Well-Being; Eco-tones; Smart Cities; Integrated Design Research (IDR) Studios; Spokane

CONTEXT

Advancements in the fields of information and communication technology have created a new era for the urban environment. Real-time data gathering and analysis is enabling us to automate routine tasks at the micro and macro level, from individual activities, to the built environment, to a city's infrastructure. Smart cities open new horizons of possibility for urban planning, by using data to identify needs, improve efficiency, and provide a higher quality of life. By collecting, monitoring, and parsing an endless stream of data, smart cities promise to continually evolve, catering more effectively to the needs of their inhabitants (Batty et al., 2012). The concept of the smart city was born in recent years from a synthesis of information and communication technologies, and a goal of understanding how these technologies might be used to address social and environmental issues, as well as improving the efficacy of city programs and services (Harrison et al., 2010). The concept of smart cities is in essence a means of integrating technologies that were designed and developed separately, as a means of enhancing community involvement and safety, social well-being, and quality of life. The term 'smart city' is one of many labels used to describe these progressive centers of technology (Hollands, 2008). Smart cities have also been identified as "wired cities" (Dutton et al., 1987), "cyber cities" (Graham and Marvin, 1999), "digital cities" (Ishida and Isbister, 2000), "intelligent cities" (Komninos, 2002), "information cities" (Sassen, 2011), and "sentient cities" (Shepard, 2011).

DATA-DRIVEN DESIGN

The Big Data revolution is changing everything at work and at home, and the built environment is no exception. The history of architecture is one of ongoing cultural reflection and commercial influence, expressing through design and materiality the driving force of each era. Information and communication technologies have transformed the landscape of urban design in our current era, especially over the past two decades. These trends have influenced every aspect of a city life, including urban infrastructure, management, social and community engagement, crime prevention, and health and safety.

Smart cities are not the result of data collection, but of how the city monitors, analyzes, synthesizes, and utilizes that data to improve social and economic services, resulting in a higher quality of life. Methods of collecting data in cities include linking GPS information with satellite remote sensing, smart phone applications, online social media networks, and interactive data systems focused on crowd sourcing. The result is a rich catena of opportunities to better understand how cities function (Batty et al., 2012). New data-driven techniques allow for a rational, objective design process that achieves high-performance, efficient designs catered to a specific geographic context. The urban built environment becomes an active participant in the life of smart cities, drawing on data to respond to the needs of its inhabitants. When architecture and urban design are driven by ongoing data collection, the result is a more flexible design process that grows and adapts to residents, much in the same way as a biological organism adapts to its local environment.

Smart cities gather data through a variety of sources, both active and passive. Sensors and cameras, digitally controlled utility services, telecommunication networks, transportation

infrastructure, and building management systems all provide sources of information that can be monitored, analyzed, and fed back into the system to manage and regulate city processes and systems. Additionally, many urban citizens use mobile computing such as smart phones or tablets, which can gather data on an individual scale, providing information about how people are navigating the city. This individualized "everyware" provides data that offers a cohesive understanding of the city across multiple scales (Hancke et al., 2013; Townsend, 2013). It can be used to evaluate existing conditions, to predict future outcomes, and to facilitate design and planning (Schaffers et al., 2011; Batty et al., 2012). The use of "Everyware" enables cities to become smarter and more controllable in fine-grained, dynamic, and interconnected ways that "improve the performance and delivery of public services while supporting access and participation" (Allwinkle and Cruickshank, 2011; Kitchin, 2014).

Smart cities are an important and contemporary topic in the literature related to urban planning and the built environment; however, little research has been done in terms of developing design methods and architecture for smart cities, and even less research exists on data-driven design processes as they relate to smart cities.

INTEGRATED DESIGN RESEARCH (IDR) STUDIOS

The core of the "smart city" is the productive use of data derived from the city, including information about its infrastructure use and residents' behaviors. Some researchers have focused more exclusively on infrastructural elements, using data and networked feedback to make these services more efficient. This has been the direction of foundational work done by the Spokane Smart City Technology Accelerator Group, composed of Avista, Itron, Cisco, the City of Spokane, and WSU. Other researchers have focused on investigating how data can be used to engage and empower citizens. The relationship between "smart systems" and "smart citizens," and the implications for city governance in this new paradigm, are currently in the process of being defined in the cities that are embracing this path.

There are always tipping points that are decisive moments in determining the future trajectories of a city. It is an exciting time for Spokane, Washington, as it stands on the cusp of such a moment. Due to the city's unique circumstances, including available infrastructure and stakeholders with a shared vision, Spokane and the city's University District are poised to become a leader in developing the smart city. The synergy between smart infrastructure and an engaged and empowered citizenry can create an engine that will attract talent, power innovation, and catalyze economic growth.

Our group, the Integrated Design Research Studios (IDR) in Washington State University's School of Design + Construction, has undertaken to study the implications of smart cities in collaboration with the Spokane University District and the Spokane Smart City Technology Accelerator Group. The IDR is composed of undergraduate and graduate studios in architecture, interior design, and landscape architecture, led by the authors of this article. Each studio is researching a unique aspect of Spokane and examining how it can begin to incorporate smart technologies. Some of these projects include the development of adaptive real-time masterplans, the investigation of how information technology can improve the health and well-being of Spokanites, the creation of interactive urban environments, and efforts toward overcoming physical, social, and technological divides that currently exist within the city. These research efforts have been broken down into four main categories: Human Interaction, Urban Metabolism, Health and Well-Being, and Urban Ecotones.

HUMAN INTERACTION

Today's cities are becoming smarter in numerous areas including energy management, mobility, infrastructure, governance, and resident engagement. For this process to work, however, good sources of data are needed. From a social perspective, there is a need to identify people

willing to participate in urban data-collection tasks and to find good incentives for participation—not only monetary rewards, but also social ones. A smart city is a humane city that has multiple opportunities for residents to develop their human potential and to lead a creative life (Winters, 2010).

There is a human aspect to a city's infrastructure, which includes (among other things) networks of knowledge-oriented workers, participants in the creative occupations, non-profit and volunteer organizations, emergency personnel, and the economy of after-dark entertainment. An awareness of these human factors is crucial to the development of smart cities. Smart phones and similar devices contribute to the development of smart cities by offering diverse opportunities for data gathering and analysis. By utilizing apps and search engines to navigate the city, residents are simultaneously providing data about our habits, activities, and location. This constant data stream can help planners and designers obtain a better understanding of the residents' needs. In addition to this active and voluntary data sharing, more passive and automated data gathering can be enacted as part of the smart city's digital infrastructure. Passive sensors and similar devices add to the ever growing data stream about the city and the life of its inhabitants. Such vast amounts of diverse, indexical data points allow for real-time analysis of the dynamic relationships between data sets in different city systems (Laney, 2001; Dodge and Kitchin, 2005; Boyd and Crawford, 2012; Marz and Warren, 2012; Zikopoulos et al., 2012; Mayer- Schonberger and Cukier, 2013; Kitchin, 2014).

As technology progresses, smart city applications will come to focus on "people in places"; in other words, to address the needs of individuals within a specific local urban environment (Schaffers et al., 2011). In accordance with this vision, researchers at IDR Studios are developing innovative ways to analyze human-generated data. The types of data examined in Human Interaction Studio projects are categorized as follows:

- Academic data from research literature reviews.
- Structured data from enterprise systems (e.g., demographic information, transportation infrastructure data, and telecommunication network data).
- Mass data derived from the use of social media, and all kinds of similar "big data" collected by Internet based media.
- "Machine-to-machine" data, which consists of information from sensors, cameras, and digitally controlled utility services.

This data provides an adaptable source of information for use with design computation tools. By relying on this data and the computational design process, the Human Interaction studio is working on a number of design enhancements for Spokane's University District, including:

Human interactive design solutions based on human observations methods (e.g. behavior mapping).

- Developing the concept of real-time city.
- Enhancing human engagement between the borders of different type of land uses.
- Promoting social events for more human face-to-face interaction.
- Encouraging walkability.
- Less stressful urban wayfinding solutions through use of signage and advanced technology (e.g., augmented reality).
- Providing a healthier environment for aging population with design solutions based on enhancing the visual memory.

- Supporting crime reduction efforts and more after-dark entertainment.
- Promoting a learning environment and encouraging the "nurturing of knowledge" (Edvinsson, 2006).
- Offering a "humane city" that has multiple opportunities for residents to develop their human potential and lead a creative life (Nam et al., 2011).
- Providing the information technology required for the growth of "smart community."

URBAN METABOLISM

To some, a city represents something that is eternal and static. Historic architecture, roads and other major infrastructure project a sense of permanence. However, a closer look reveals a nested set of dynamic systems of people and resources in a state of constant flux. Recently, the notion of urban metabolism has shown promise in understanding and illuminating possible solutions to the complexity of the city. Urban metabolism concerns itself with resource flows—energy, water, food, material, and waste—in, through and out of the city. These resources are essential to the functioning of the city and the health and well being its citizens. The potential of real time data and analysis of the Smart City provides tools in which to develop dynamic urban metabolic models. The ability to understand and predict metabolic flows that constitute the city will allow policy makers to design in resiliency to the systems and create ways in which to more effectively utilize them for the benefit of citizens.

Smart Systems provide technological means to manage and adapt these resources flows to our changing needs. The potential of these Smart Systems are blunted if the behavior of the citizens do not also adapt. Real time data analysis and visualization married to ubiquitous smartphone technology offers the potential to reveal to the citizens the metabolism of the city and to understand how their behavior affects the well being of the city. The IDR Metabolism Studio seeks to understand the urban design implications of aligning Smart Systems and Smart Citizens through an adaptive master-planning framework to create a more resilient and responsive city.

HEALTH AND WELL-BEING

According to the World Health Organization, a "healthy city" in one that is "continually creating and improving those physical and social environments and expanding those community resources which enable people to mutually support each other in performing all the functions of life and in developing to their maximum potential" (World Health Organization, 1998). As cities become more technologically enabled, there is ever increasing potential to track health indicators and to shape initiatives that promote healthy behaviors and environments. The Health and Well-Being Studio is based on the premise that the people occupying smart cities are "citizen inhabitants"—motivated and empowered to actively participate in their personal, physical, social, and community well-being. Technologies focused on human health, behaviors, and environments will give the inhabitant access to relevant data sets and applications that may, for example, help them to make proactive health decisions, or encourage social connections and community involvement. An important objective is to equip the district inhabitants to have a dynamic, interactive relationship with the immediate physical environment, enabled through bi-directional feedback loops and user controls. At the room scale, this might include intelligent environmental systems that respond to the inhabitant's needs and preferences. At the street scale, one could imagine exterior lighting that an inhabitant can influence for safety or even for creative expression. As the World Health Organization suggests, the definition of a healthy city encompasses a broad array of physical and social factors. The overarching goal of this studio is to grapple with the potential of dynamic, evolving human-centered technologies that can support a healthy city.

The Health and Well-Being Studio begins by mapping existing conditions and health indicators within the (site name). Readily available data sets include:

- Inventories of public infrastructure
- The quality and availability of shelter
- Access to food, green space, medical services, and transportation
- The availability of recreational activities, social spaces, and creative outlets
- Activity of community groups
- Occurrences of environmental hazards including various types of pollution and threats to personal safety

A summary analysis of the mapping exercise is combined with a literature review to establish an understanding of health "promoters and detractors" within the district. These determinants are considered within Maslow's hierarchy of needs to create a working diagram that helps to situate health and well-being indicators and associated smart city initiatives (Figure 1). Following this, each student in the Studio focuses on an individual design problem and proposal that logically follows the overall Studio goal—creating data-driven designs that cultivate engaged, aware, and responsive city inhabitants. The student ideas cluster in the following areas: social / community well-being (activation of social centers), interactive information technologies (interactive objects that supply information, collect data, entertain, educate), and support for physical well-being (transit and nature systems).

1

Figure 1: University District Maslow Diagram

URBAN ECOTONES

Smart cities are connected cities—connected in both the technological sense and in a deeper ecological and human-oriented sense (Harrison et al., 2010). The goal of the Urban Ecotones Studio is to determine how the technological realm can help drive efficient and poetic interventions within the physical city to help improve connectivity. The concept of an urban ecotone is a metaphor drawn from ecology. An ecotone is an edge, transition zone, and linkage between two distinct ecosystems, where a rich diversity of species and habitat can be found (Kark, 2013). Ideally then, an urban ecotone is a space that brings physical, social,

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economic, and cultural aspects of adjoining communities together to form a dynamic linking space (Gaffney, 2009).

This studio will specifically work on establishing an urban ecotone between Spokane's University District and the East Central Neighborhood, an historically disadvantaged and disconnected inner city neighborhood. Working with community partners, this studio will seek to define the urban ecotone condition through the research of relevant literature as applied in previous field conditions, as well as through developing and gathering relevant data points that can describe both existing and desired conditions in Spokane. These data points will include key, but often unconnected ideas such as access to food, education, employment, and culture; inclusion in the life of the city; and health as it relates to the physical environment.

There are many physical, social, and psychological barriers to creating healthy urban ecotones. Massive transportation infrastructure can cleave cities into distinct areas. The rail line in Spokane is notorious for hosting a large number of oil-carrying "bomb trains" that can pose significant social and ecological risks. Historic ecological patterns in the city have been obliterated after a century of a command-and-control approach to nature; the naturally functioning ecotone between the southern hills and the Spokane River, for example, has been eliminated. Meanwhile, decades of neglect of inner-city neighborhoods has created immense trust divides among the residents.

Once the current urban ecotone condition in Spokane has been defined through our research and data collection, the design proposals in the IDR Ecotone Studio will proceed to offer specific opportunities for the interface between the University District and the East Central Neighborhood. These proposals will include:

- Development of appropriate interventions designed to begin to eliminate the described barriers and build interaction between communities.
- Creating and fostering a substantive, functioning, poetic landscape of connection, inclusion, and healing.
- Introducing multi-functional landscapes that serve as bio-physical infrastructure and connectors.
- Enhancing perceptions of safety.
- Connecting East Central residents to the educational, social, cultural, and economic opportunities of the University District.
- An active "Internet of things" approach to intelligent land management, with goals such as improving soil and water quality and limiting the potential hazards of rail lines and vehicle routes.
- Restoring the functioning of ecological systems in the ecotone, from the southern hills to the Spokane River.
- Encouraging alternative transportation modes.
- Engaging citizens to assist in the real-time monitoring of landscape and community health.

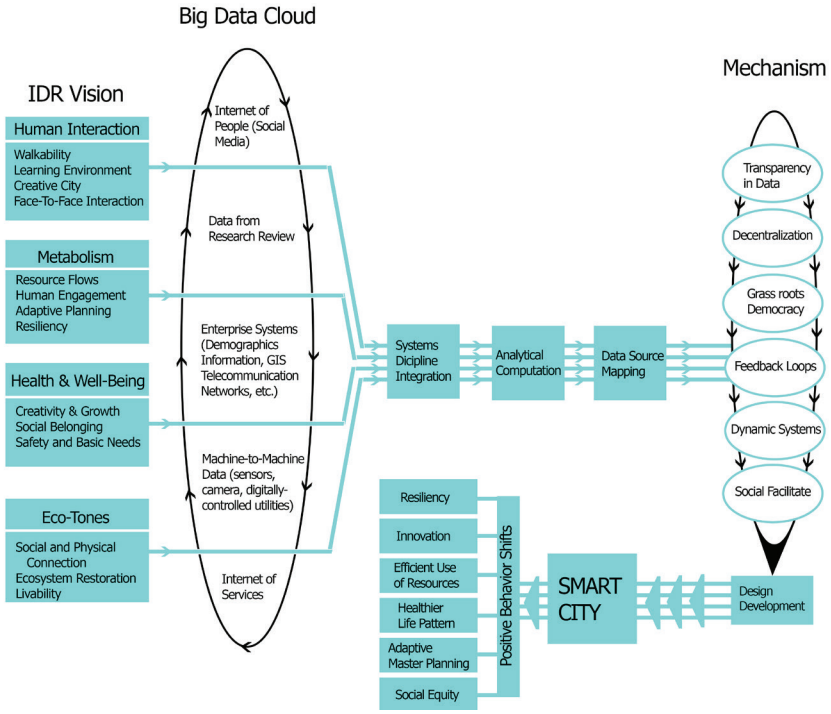
SUMMARY

Just as smart cities are made possible by the incorporation of "big data" analytics into the design of city systems and infrastructure, researchers at IDR Studios are achieving their vision through data mapping, synthesis, and design development. Students in the studios gather data through multiple diverse sources: literature reviews, enterprise systems, and

machine-to-machine data resources, to name a few. Individual city residents can add to the data stream through their use of social media, online search engines, apps personalized based on user preference, and geolocation tracking of our movements. Reviewing existing academic literature on topics related to smart city design provides a robust foundation for studio design development (Figure 2).

Studying data from enterprise systems allows students to understand the existing demographic conditions in the city, and to begin to visualize ways to improve these conditions through their design research. Automated machine-to-machine systems can provide real-time data, day or night, which is then analyzed, synthesized, and incorporated into designs to improve existing conditions. This wealth of data can be reviewed from different angles, and mapped in order to determine which data sets interact with and contribute to others. This information leads to better design development with the goal of providing smart city solutions to enhance the possibilities and quality of life of the city's residents.

Integrated Design Research Studios incorporates multiple disciplines in a collaborative goal-driven environment, which encourages students to evaluate and analyze data drawn from existing conditions, combining creative thinking with technological advancements to design a smarter built environment for the city. The Spokane Smart City Technology Accelerator Group will continue to analyze data gathered from Spokane's systems, processes, and inhabitants, and to work with the next generation of creative minds to improve the University



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District, and ultimately, the city of Spokane as a whole.

Figure 2: IDR Design Process for Smart Cities

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