Digital City Testbed Center: Using campuses as smart city testbeds in the binational Cascadia region

Jonathan Fink*†
*Digital City Testbed Center, Portland State University, Portland, OR USA; jon.fink@pdx.edu
† Department of Earth, Ocean, & Atmospheric Sciences, University of British Columbia, Vancouver BC, Canada

***Abstract*—The collection and use of digital data by "smart city" programs raise complex operational and ethical questions that can best be addressed through carefully-monitored pilot studies before urban innovations are more widely adopted. We have created a network of single-owner campuses (academic, government, corporate and nonprofit) in the Cascadia megaregion that connects Portland (OR), Seattle (WA) and Vancouver (BC), where smart city products and services can be evaluated before deployment in neighborhoods and business districts. On the five initial campuses, we are co-locating assemblages of up to a dozen technologies through which issues of data interoperability, management, privacy and monopolization can be explored. The initial research and policy goals of this network are to educate the public about smart cities, improve accessibility for populations with disabilities, prepare city residents for natural disasters, and monitor urban tree canopies so they can better mitigate the urban heat island effect. If replicated in other regions, this testing approach can accelerate cities' responsible integration of data science solutions that can address both local and global problems.**

Keywords—smart city, Cascadia, testbed, urban analytics

I. Shaping the Smart City Landscape in the U.S.

Cities are increasingly recognized as the world's least politicized and most functional scale of governance [1]. Mayors and city council members personally experience the impacts of their decisions more frequently than their state, provincial, and national counterparts. Cities are thus well-suited to incubate new ideas related to both policies and technology. Regionally distinct economic development and cultural ecosystems can produce novel solutions to common problems. For instance, Pittsburgh pilots new digitally enhanced snowplow strategies, while Miami monitors sea level rise and flooding. Companies thus lobby municipal officials to try their digital services, solicitations that cities lack the staffing to evaluate. As a result, new solutions for common city problems can struggle for visibility in a diverse set of marketplaces.

In response, single-vendor smart-city solutions emerged, such as Toronto's Quayside development, overseen by Sidewalk Labs [2], which contracted to provide multiple digital services in exchange for access to associated data. Although public backlash about data ownership led to the project being abandoned [3], Sidewalk's investment promised innovations they hoped to market elsewhere, and that Toronto expected would improve their residents' and visitors' quality of life.

In a contrasting approach, cities, either independently or in partnership with academic, NGO, and private sector partners, oversee development of their own digital products and services, mixed with those from private vendors. For example, Tel Aviv's DigiTel [4] focuses on citizen engagement, providing residents customized, discounted services when they register. The city gains a communication channel with and information about its residents, who in turn get benefits like access to babysitting, yoga classes, and early school registration for their children. DigiTel attracts a majority of Tel Aviv's citizens as subscribers who in turn gain trust for city government. Programs like this result in Tel Aviv being seen as a leading urban innovator.

Cities' interest in digital technologies expanded dramatically in the 2010s, due to growing availability of smart phones, cloud computing, high-speed wireless, and broadband. This period also saw increased concerns about urban risks due to climate change, natural disasters, and terrorism. Initial city responses were disconnected and uncoordinated, but programs like Rockefeller Foundation's 100 Resilient Cities [5], organizations like Urban Sustainability Directors' Network [6], and standards like ISO 37120 [7] from University of Toronto's Global Cities Indicator Facility [8] all sped up information exchange among cities. However, as these technical programs became more widespread, so did concerns about how digital urban data sets might be abused. Governments could no longer take residents' trust for granted, nor could companies assume that cities would give them free reign.

Three particularly influential federal smart city initiatives emerged in the U.S: Department of Commerce's Global City Teams Challenge (GCTC) [9], started in 2014; the White House launch of the MetroLab Network (MLN) of city-university pairs in 2015 [10]; and the Department of Transportation's Smart City Challenge (SCC) competition held in 2016 [11]. The GCTC, overseen by the National Institute of Standards and Technology, links federal, corporate, and municipal players from the U.S. and more than a dozen other countries. It began as an annual competition among cities to come up with novel digital solutions to common city problems. Organized today around topical "superclusters," GCTC convenes meetings and small workshops, all designed to promote the exchange of best practices and the development of standards for urban data use.

In 2015, Carnegie Mellon University and the White House Office of Science and Technology Policy established the MLN, an association of nearly two dozen city-university partnerships committed to using technology to jointly address local problems while accelerating the exchange of urban innovation. Now an independent nonprofit, MLN is one of the primary forums for connecting university faculty and campus operations staff with city officials and community groups concerned about both the promise and risks of urban digital innovation.

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The most transformative smart city event in the U.S. was the SCC, a competition offering $50M to the city that could rapidly propose "an integrated, first-of-its-kind smart transportation system that would use data, applications, and technology to help people and goods move more quickly, cheaply, and efficiently." With a short fuse and large payout, the SCC motivated city governments and partners to rapidly organize how they incorporate tech into their transport planning and operations. Columbus OH beat 77 other applicants. The six other finalists (Austin TX, Denver CO, Kansas City MO, Pittsburgh PA, Portland OR, and San Francisco CA) self-funded parts of their proposed agendas, with all seven agreeing to exchange best practices. USDOT originally compiled 100 projects in a list that has since grown to over 740 [12].

II. Development of Portland's Smart City Ecosystem

Strongly influenced by the SCC, Portland and Portland State University (PSU) became founding members of MLN and early contributors to GCTC's transportation cluster. Following Columbus's win, Portland, globally known for environmental policies, centralized its digital innovation in the Smart City PDX [13] office, which works with outside partners to address priorities set by Bureau chiefs and the City Council. As in many cities, this experimentation initially focused on transportation. In the 1980s, Portland had been the first U.S. city to redirect federal highway funds to mass transit, substituting light rail for proposed freeways. In 2005, local transit agency TriMet developed the General Transit Feed Specification (GTFS) standard [14] making transit information available to navigation applications like Google Maps. In 2019 Portland, Metro regional government, and TriMet hired Sidewalk Labs to study traffic flows using a data set derived from tracking movement of Android phones. Portland also maintains some of the nation's highest rates of adoption of hybrid and electric vehicles, and bicycle commuting.

In addition to creating Smart City PDX, Portland and the Technology Association of Oregon (TAO) organized a region-wide, multi-sector Smart City Committee with participation by engineers, architects, urban planners, tech firms, city officials, NGOs, academics, and startup companies. Quarterly meetings, with 25-75 attendees, have strongly unified the community, identifying issues that subgroups can pursue, and introducing startup companies and new partners to the group.

Another SCC offshoot was closer ties between the City and PSU, whose largest federal grant ($35M over ten years) supports one of USDOT's five University Transportation Centers [15], a consortium that includes the City's Bureaus of Transportation (PBOT) and Planning and Sustainability (BPS). Smart City PDX shares a building with PSU and more than half of its staff members are PSU alumni.

In 2018, PSU held an internal competition to create two Centers of Research Excellence that could build on institutional strengths. Based on close partnerships with the City, PSU selected a smart city program, the Digital City Testbed Center (DCTC) [16], as well as the Homelessness Research and Action Collaborative. The rest of this paper discusses opportunities that the DCTC provides to address urban data issues.

III. The Digital City Testbed Center (DCTC) Network

The DCTC seeks to help cities, companies and the public evaluate technologic and policy characteristics of urban innovation. Set up as a partnership among PSU, Portland, and TAO, DCTC is building a network of campus testbeds where digital city applications can be tried before being deployed more widely, and where research can be conducted on specific applications for which technology holds promise, like accessibility or energy conservation. Single-owner campuses are able to make faster decisions than neighborhoods subject to city regulations and public vetoes.

The first five nodes of the DCTC network are the campuses of PSU, University of British Columbia (UBC), University of Washington (UW), Oregon Museum of Science and Industry (OMSI), and Portland International Airport (PDX). This diversity of locations and campus types, all within the Cascadia megaregion that links Vancouver, Seattle, and Portland, offers different boundary conditions for evaluating data issues. These three metros have much in common--well-educated populations with a strong affinity for the natural environment, technology-based economies originally built on natural resource extraction, an unstable geologic setting, housing affordability crises, and progressive social agendas. At the same time, they differ in the relative importance and influence of three key attributes: high-tech industries (Seattle > Portland > Vancouver), community engagement (Portland > Vancouver > Seattle), and municipal government (Vancouver > Seattle > Portland) [Michael Armstrong, pers. comm., 2018].

PSU’s 55-acre campus is fully immersed in the City of Portland, with all roads, streetlights, utilities, transit and municipal services being provided to the university by outside organizations. These features make it at once the most realistic and the most challenging campus testbed. Smart transportation evaluation requires coordination with local, regional, and state agencies. Public safety innovations need to be conducted with the Portland Police. Only building operations and energy innovations lie fully in the purview of the university. Equally important, the attitudes of city residents about the use of digital technologies must be taken into account.

At the other end of the spectrum, UBC's 990-acre campus is a nearly completely self-contained city, with municipal services other than transit all provided by the university. The campus sits on an elevated peninsula about eight miles from downtown Vancouver, surrounded on three sides by the Pacific Ocean and separated from the suburbs by a half-mile-wide stand of redwood forest. Recognizing this unique opportunity, the UBC administration and faculty set up an extensive “campus as a living lab” agenda in the early 2000s. Initially focused on helping the university attain its ambitious sustainability goals through novel energy generation and conservation techniques, these assets have more recently been combined with digital technology in order to make the campus function as a "smarter" city. For instance, the Aurora Connected Vehicle Technology Testbed [17] combines traffic monitoring, a proposed autonomous shuttle [18], and a $3.7M 5G deployment from Rogers Communications [19]. The UBC testbed draws on the expertise of dozens of faculty members in engineering, architecture, computer science, business and law and, critically, on the strong support of the leadership and staff of the academic and business operations units. Although Portland-based, DCTC helps UBC access added resources, expertise, and connections.

University of Washington has three campuses, in Seattle, Tacoma and the suburban town of Bothell. DCTC is partnering with the Taskar Center for Accessible Technology [20] and the Urban@UW program [21], both located on UW's 703-acre main Seattle campus. This testbed shares attributes with both PSU and UBC. Five miles from Seattle's Central Business District, the campus has a well-developed network of bicycle paths and good multi-modal transit access including over a dozen bus lines and the Link light rail. With a campus core that is partly separated from nearby residential and business districts, UW manages some of its own urban functions like public safety and building operations, but others, like energy and water supply come from the City. Faculty in UW's Information School and Paul G. Allen School of Computer Science and Engineering work on the data science aspects of smart cities, in collaboration with colleagues at UBC and PSU.

DCTC's fourth campus, the Oregon Museum of Science and Industry (OMSI), is an 18-acre site with excellent transit connectivity, immediately across the Willamette River from downtown Portland and PSU. The Museum's eleven acres of parking lots are being master-planned for a 3-million square foot mixed-use commercial/residential development scheduled to begin construction in 2021. OMSI's current buildings and over one million annual visitors offer exceptional opportunities to try out, and educate the public about, new digital technologies and services. Equally promising is the prospect of weaving these innovations into the design of the new real estate development. Immediately north of the OMSI campus is Portland's 600-acre Central Eastside Industrial District, housing mostly small, light manufacturing, food preparation, and arts-oriented companies experimenting with new techniques like 3-D printing and artificial intelligence, recently supplemented by a few larger high-tech firms (Autodesk and Apple). This combination of educational outreach combined with future-oriented manufacturing increases the potential of the OMSI site to serve as a model smart city incubator.

The 3,000-acre Portland International Airport (PDX) is DCTC's fifth campus testbed. Consistently ranked "the most popular airport in the U.S." by various travel magazines and surveys [23], PDX is recognized as an innovator in both service delivery and technology. DCTC is collaborating with PDX on the deployment and testing of various applications designed to assist passengers with disabilities navigate through the terminal, and educate the public about the airport facility, particularly during its current major renovation. DCTC also hopes to take advantage of PDX's strong networking with other leading airports across North America.

IV. Technologies being tested on DCTC's campuses

One of the main goals of the DCTC is to assist cities and the public evaluate new digital technologies. Here we briefly describe four example applications from startup companies Sensible Building Science [24], Downtown.ai [25], Hello Lamp Post [26], and Numina [27], along with one (AccessMap) from a research center at UW [28]. In the following section, we discuss policy issues these applications help us consider.

A. Sensible Building Science

A primary motivation for deploying digital technologies in cities is to help them reduce CO_2 emissions. Because buildings account for up to 40% of a city's carbon output, finding ways to more efficiently heat, cool and light them is a key sustainability objective. As an example, motion-detection sensors have been used for more than two decades to turn off lights when people leave a room.

Vancouver-based Sensible Building Science takes this approach several steps further by using the growing ubiquity of Wi-Fi systems as a way to reduce energy consumption in parts of buildings that have fewer occupants. Sensible's approach is based on the recognition that high-end routers from companies like Cisco are capable of calculating occupancy in rooms and hallways based on the number of Wi-Fi-enabled devices that are constantly probing for signals. Sensible calibrates and links this occupancy information directly to building management systems from companies like Siemens or Johnson Controls in order to reduce the use of energy in places where people are largely absent. When deployed on the UBC campus, Sensible was able to reduce building energy consumption by 5-22%.

DCTC is now working with local utility Portland General Electric (PGE) as well as Cisco and Siemens to install Sensible's system on the PSU campus, to reduce local energy consumption, but also as a pilot to demonstrate potential demand-side-response (DSR) benefits to large clients like Nike and Intel. Currently, PGE has arrangements with many of its largest users that allow it to cut back a certain amount of power during periods of peak demand. These contracts are fixed--during a DSR event, power levels are always reduced the same amount in the same locations, independent of how that space is being used. With Sensible's approach, PGE customers could preferentially cut more power in less-occupied places, leading to larger savings with less impact on comfort. Scaled up, this strategy might let larger utilities like California's Pacific Gas and Electric reduce their consumption without resorting to as many of the blackouts they are currently causing in order to reduce the risk of wildfire ignition from high-tension lines during windy conditions [29].

B. Downtown.ai

Downtown.ai is a second Vancouver startup that uses anonymized cell-phone triangulation data purchased from data aggregators to map out human movement in cities. DCTC has contracted with Downtown.ai to determine the paths and modalities that bring people to the UBC campus from throughout the metro Vancouver region. Downtown.ai will also map where these visitors subsequently walk or bicycle to from bus stops or parking structures once they arrive on campus. This information is invaluable for forecasting and right-sizing future on-campus parking and transit services. Downtown.ai claims that their sampling and aggregation algorithms serve to effectively anonymize the identities of the owners of the devices whose pathways they are mapping.

C. Hello Lamp Post

Gathering information about the concerns the public has about the benefits and risks of deploying technology in cities can be difficult, especially if it needs to be obtained through traditional survey methods. A novel way to collect and transmit information from and to the public comes from London-based Hello Lamp Post (HLP). HLP allows people to exchange SMS, Facebook Messenger and WhatsApp messages with pieces of urban infrastructure, including lamp posts, street signs, park benches and garbage receptacles. HLP designs dialogues that playfully engage people, collecting their responses to embedded questions. For instance, a street sign might ask a pedestrian how far they've traveled from, what they see nearby, and what their opinion is of some local landmark. These narratives can change dynamically in response to earlier comments, for instance allowing the object to ask the person to confirm some view or observation made by others. Although originally intended solely to entertain, HLP dialogues can also collect information from and/or deliver it to participants, serving as an informal survey instrument. HLP customers, including cities, shopping centers, museums, and universities, can then get access to a valuable database of geolocated questions and responses.

In 2019, after being introduced to HLP by the DCTC, UBC's Parking Department installed the service on most of the parking meters on campus (Fig. 1) for a novel application--earthquake preparedness. Because UBC's meters have backup power, they can act as a resilient source of emergency information if a major earthquake or other natural or manmade disaster were to knock out power and cell phone reception on campus. However, to get the UBC community to see parking meters and other objects as having this capability, HLP dialogues need to be engaging as well as informative. These narratives are currently being designed to both inform people about earthquake risk and gauge their existing knowledge.

D. Numina

Traffic monitoring has long been practiced by governments through manual counting, in- and on-road sensors, and video and still cameras. New "smarter" approaches combining digital video, LiDAR and AI have been proliferating over the past several years. One of these is offered by Numina, a Brooklyn (NY) based startup that mounts specially equipped video cameras on municipal light poles and uses image analysis and AI to differentiate types of vehicles and pedestrians, generating maps and data sets that show the speeds and locations of different objects. Video analysis is all performed "on the edge," so the only information transmitted from the cameras are different-colored tracks representing moving objects of different types (Fig. 2).

In 2018, as part of the follow-up to the Smart City Challenge, PBOT contracted with ATT, GE, and Intel to create a comprehensive new Traffic Sensor Safety Project, intended to help achieve the city's Vision Zero goal of reduced pedestrian fatalities at several of its most dangerous intersections. At $500K, this "CityIQ" program was one of the most expensive smart city experiments in the U.S. At roughly the same time, the Smart City PDX office began exploring less costly solutions that could be compared with anticipated results from CityIQ, one of which was from Numina. After CityIQ's launch in early 2019, DCTC agreed to co-fund with Smart City PDX a Numina pilot on the PSU campus, looking specifically at near collisions of motor vehicles with bicycles and pedestrians, as well as providing baseline information for a future congestion pricing scheme. However, frustration about persistent problems with the more expensive CityIQ program led PBOT to rescind permission for PSU and Smart City PDX to install the Numina cameras on city light poles. Alternative mounting tactics were too expensive, so DCTC sent the cameras to UBC, where they could be integrated into the Aurora Connected Vehicle Testbed. Beginning in summer 2020, the Numina cameras will begin tracking interactions among pedestrians, bicycles and vehicles on the UBC campus.

E. AccessMap

While most smart city applications focus on municipal infrastructure (buildings, roads, bridges, transit, electrical grids, water systems), a few try to meet the more specialized needs of particular populations. A notable example is accessibility technology, designed to help individuals with physical and cognitive disabilities find their way around a city. Expensive linked video-audio systems like Aira [30] and Indoor Explorer [31] combined with indoor GPS and LiDAR-based digital maps allow people with low or no vision to navigate complex, multi-modal routes through cities.

Fig. 1. Hello Lamppost parking meter on the UBC campus.

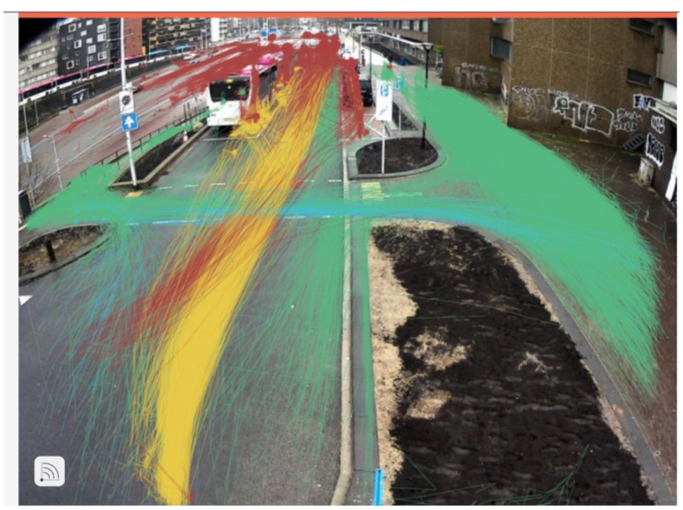

Fig. 2. Colored tracks from Numina sensor representing cars (red), buses (yellow), bicycles (blue), and pedestrians (green).

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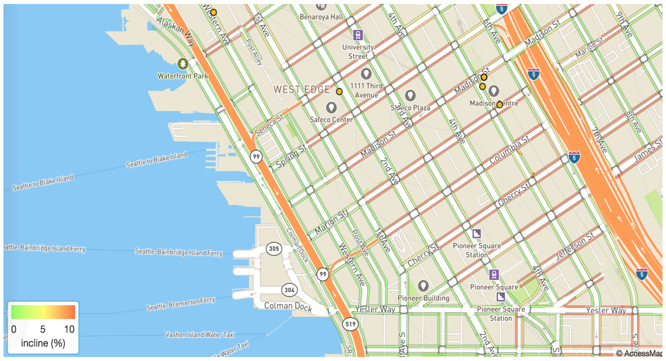

Fig. 3. AccessMap representation of downtown Seattle with sidewalk colors coded to slope (red is steeper, green is flatter),

People who use wheelchairs can also take advantage of digital applications. AccessMap is a cell phone app that provides an overlay for Open Street Map showing the slope of urban sidewalks (Fig. 3). For instance, a person who knows that his or her wheelchair can only negotiate slopes of up to three degrees can use AccessMap to plot out a gentler route from point A to point B, in some cases taking advantage of elevators in high-rise buildings that can take a person from a street on one side of a building to a higher or lower one on the other side. AccessMap has been deployed in downtown Seattle and on the UW campus and is currently being evaluated by PSU and UBC.

V. Discussion: Concerns raised by DCTC applications

The five applications just described can provide clear benefits to city dwellers, municipal governments and companies. Programs like the Digital City Testbed Center can help these three groups determine which services and products are best suited to a particular location or set of conditions. DCTC uses campuses for initial deployment because their decision-making is simpler and commonly faster than that of a city as a whole. But each of these examples can also raise questions about monopolization, lack of interoperability, privacy, equity, and data security, concerns that threaten to prevent technological solutions from realizing their potential. Here we explore some of these issues through the lens of DCTC's current application set.

Sensible Building Science uses proprietary software that combines information collected by different brands of Wi-Fi routers and building control systems in order to reduce energy consumption. Because it is not tied to a single vendor's products, it can avoid concerns about monopolization. Similarly, by having router-derived occupancy outputs serve as inputs to building control systems, Sensible promotes multi-vendor interoperability. On the other hand, by interacting with the IT systems that control buildings' HVAC and lighting, Sensible could potentially open up a new security vulnerability. For this reason, the software has been designed to work entirely inside the client's firewall, precluding any additional exposure to outside intrusions.

Downtown.ai manipulates data sets collected, aggregated, and anonymized by third-party cell-phone providers. However, as has been pointed out in numerous articles, the techniques used to conceal the identities of people included in large data sets are becoming increasingly inadequate as computation becomes more powerful [32]. Analysts that want to determine who owns a phone whose geolocated pathway has been included in a large database can commonly find a way to do so. After purchasing a dataset from a telecom company, Downtown.ai can further manipulate it before analyzing or releasing it to its clients. Because most members of the public lack the resources to develop or assess anonymization techniques, it is incumbent upon companies like Downtown.ai to take full responsibility for protecting the privacy of all people whose data they are using.

In contrast to Downtown.ai, Hello Lamppost is less likely to trigger red flags among privacy advocates. People sending text messages to a parking meter or a park bench would not be expected to reveal deep personal secrets. However, the responses collected and assembled by HLP into a database are affiliated with a phone number, FB Messenger or WhatsApp account name, as well as a location. After a person's first interaction with HLP, they receive a link to the company's privacy policy. Given the well-publicized breaches of databases managed by major corporations and large government agencies, it would not be unreasonable for individuals to become reluctant to share their opinions with cell-phone applications, even playful ones like HLP. In order to preserve the public's trust, companies that routinely collect potentially identifiable information need to push for the development of anonymization standards and protocols, ideally involving certification agencies like ANSI or ISO.

A second potential concern can arise from UBC's plan to use Hello Lamp Post as a means of communicating with their community about a potentially deadly topic like disaster preparedness. As with any technology-dependent public service, it is essential that all prospective users have access to the minimal equipment needed to receive the information. HLP has the advantage of not requiring a separate application—it relies on communication methods like text messaging that nearly all cell phone owners are familiar with.

Because it depends on video camera input, Numina is the most likely of the five described DCTC applications to raise privacy concerns. However, the company's founders were well aware of these risks and designed their software to follow principles of "Privacy by Design" and "Intelligence without Surveillance." Before any data is sent to or stored on Numina's servers it is fully anonymized "at the edge." The street objects that Numina's video cameras record (vehicles, people, trash bags) are translated into non-identifiable, colored tracks before leaving the camera. This level of corporate attention and responsibility is required for smart city applications to circumvent the restrictions imposed by public-opinion-driven municipal regulations. However, even with these accommodations, some community members may remain skeptical. As an example, Portland's City Council is currently considering the most restrictive facial recognition software limitations in the U.S. out of fears that police departments and private businesses will misuse the information obtained by video surveillance. Balancing these understandable concerns with the benefits of ongoing innovation is one of the greatest challenges faced by smart city proponents.

The final application raises a different set of issues. AccessMap is aimed at populations with physical disabilities. In addition to addressing common threats to privacy and data security, accessibility tech developers need to also consider the physical safety and well-being of their users, who rely on applications to fill in for gaps in their perception or mobility. At the same time, by targeting software to particular groups with special needs, developers can move closer to the ideal of "designing physical and virtual spaces, and products and services, to address the inherent diversity of people."[33] This universal design goal, which is being increasingly recognized by large technology companies, governments, and nonprofits, can help assure that smart cities are also equitable cities.

One of the DCTC's strongest selling points is its collaborative development. Although originally established by PSU, it has become an unofficial testing mechanism for digital innovation for the City of Portland, the Technology Association of Oregon, UBC, UW, OMSI, and Portland International Airport. In addition, it offers large and small companies as well as nonprofits novel opportunities to interact with each other in multiple settings, revealing new synergies and applications. By distributing its activities across the neighboring metropolitan areas of Portland, Seattle, and Vancouver BC, DCTC provides enhanced ways to integrate economic development across the entire binational Cascadia megapolitan region.

VI. Conclusions

Digital technologies hold great promise for improving the functioning of cities and the well-being of their residents. Making cities "smarter" can help achieve additional societal goals like reducing carbon emissions, preparing people for (or recovering from) natural disasters, improving accessibility for populations with disabilities, and relieving the shortage of affordable housing. Governments, companies, nonprofits and universities are all striving to meet these aspirations. The Digital City Testbed Center is an example of an academic initiative that seeks to accelerate progress by trying out new digital applications under relatively controlled conditions on single-owner campuses across a binational region. These deployments offer opportunities to evaluate both the benefits and risks of urban technologies.

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