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Human-Smart Environment Interactions in Smart Cities: Exploring Dimensionalities of Smartness

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Abstract: In the context of the challenges facing human computer interaction (HCI) on the one hand and the future Internet on the other, the purpose of this study is to explore the multi-dimensionality of smart cities, looking at relationships and interdependencies through correlating selected dimensions of smartness. Key dimensions of smartness are identified for exploration in the context of smart cities in this work through a review of the research literature. Methodologically, this work combines an exploratory case study approach consisting of multiple methods of data collection including survey and in-depth interviews, with an explanatory correlational design. In terms of results, the main findings of this work shed light on the relationships between selected dimensions of the multi-dimensionality construct of smartness in data-rich urban environments. This work is significant in that it provides correlational information for smart city dimensionalities while contributing to the research literature in this domain; uses a hybrid case study and correlational design in relation to the study of multi-dimensionality; and, opens spaces for the study of innovative urban initiatives, while taking the ideas and experiences of people from many sectors into consideration.

Keywords: citizen engagement; correlation; future internet; human-smart environment interactions; innovation; interactive public spaces; learning cities; livability; relationships; smart cities; sustainability; transient interactions; urban data; urban interventions; walkability

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1. Introduction

In the context of a series of human computer interaction (HCI) grand challenges identified by Stephanidis et al. [1], the claim is made that "interactions in smart environments are in the process of being radically transformed", such that "technological environments will not be simply the smart home or workplace but entire smart cities". This is important, because such transformation points to the potential for many dimensions to be involved in interactions in smart cities as smart environments. Komninos [2] articulated the relevance of the future Internet space to smart cities in relation to the Internet of Things (IoT), sensors, cloud computing and the like, forming "innovation ecosystems" at the intersection of citizen empowerment and smart environments. More recently, Komninos [3] expanded on the notion of smart ecosystems enabled through the Internet, web platforms, big data and analytics and civic technologies, among other elements that make it possible for "people, institutions and machines to connect, collaborate and resolve complex problems". Komninos and Kakderi [4] argue for the importance of complementing algorithmic logic with governance that accommodates "citizen engagement and collaboration networks that generate innovations for better cities". As such, the purpose of this paper is to explore the multi-dimensionality of smart cities looking at relationships and interdependencies through correlating selected dimensions of smartness, keeping in mind *human-environment interactions (HEI)*, said to be one of the seven HCI grand challenges. This work extends the notion of HEI to human-smart environment interactions (HSEI), acknowledging that humans have always interacted with environments, whereas now the key difference involves more aware humans interacting with and within more technologically infused and aware environments.

A conceptual framework is developed for operationalization in this work through a review of the research literature for dimensionalities and multi-dimensionalities of smart cities, focusing on the constructs of openness and innovation, in support of the potential for increased citizen engagement and collaboration. The review of the research literature, together with the theoretical perspective developed in this work, gives rise to the key research question under exploration in this paper—*What is the nature of the relationship between selected dimensions of smartness in human-smart environment urban interactions?*

This work is significant in that it contributes to the research literature for smart cities; explores the HCI grand challenge of human-environment interactions (HEI) in smart cities; and, formulates an HSEI conceptual framework for smartness and dimensional relationships in smart cities. Methodologically, the research design for this work involves a hybrid approach while using an exploratory case study consisting of multiple methods of data collection, including survey and in-depth interviews, combined with an explanatory correlational design. The main findings of this work shed light on the relationships between selected dimensions (e.g., openness and innovation, etc.) of the smartness construct and its' multi-dimensionality in data-rich urban environments and regions. The main conclusion highlighted in this work focuses on the importance of relationships between dimensions of smartness in relation to smart city elements, such as walkability and liveability, which contribute to an understanding of multi-dimensional components in human-smart environment urban interactions that are associated with data in public spaces, more aware people, and more aware environments.

2. Dimensionalities and Multi-Dimensionalities in Smart Cities

Wong, Law, and Huang [5] note that, "a construct is multidimensional when it consists of a number of interrelated attributes or dimensions and exists in multidimensional domains" drawing on the work of Law, Wong, and Mobley [6]. In developing the multidimensional domain of the smart city, Nam and Pardo [7] conceptualize three dimensions of a smart city as technology, people, and institutions, while Gil-Garcia, Zhang, and Puron-Cid [8] conceptualize the construct of smartness in the institution of government as multidimensional, consisting of 14 dimensions. As such, Figure 1 provides an illustration of how the literature review that follows is organized to categorize elements that are associated with the multi-dimensionality of smart cities, including the exploration of frameworks and dimensions, contributing to evolving and emerging directions based on selected elements of the dimension of smartness (where information sharing figures strongly [8]), such as citizen-centricity, citizen engagement, openness, and innovation. This review and background opens spaces for the evolving of frameworks, such as human-environment interactions (HEI) to that of human-smart environment interactions (HSEI) in support of innovation and learning and urban data intervention potentials.

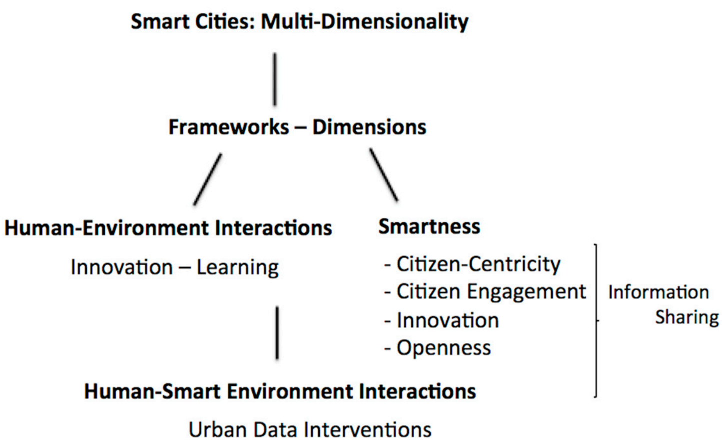

Figure 1. Categorization and organization of smart cities and multi-dimensionalities.

2.1. Review of the Research Literature

A review of the research literature is provided for the dimensions and multi-dimensionalities of smart cities, followed by emerging and evolving interactions in relation to human-smart environment interactions (HEI) in public spaces. A summary of the literature review is then provided in tabular form, followed by the formulation of a conceptual framework, which is based on the research literature, and operationalized for use in this paper. Literature was selected for this work that would address evolving, emerging, and interdisciplinary understandings of smart cities, particularly with reference to smartness. The smart cities concept presented in this paper seeks to encompass the technical, the urban context, and the people component in an interactive dynamic.

2.1.1. Dimensions and Multi-Dimensionalities of Smart Cities

Giffinger et al. [9] provided an early, "classical" approach to smart cities as urban regions encompassing smart economy, smart people, smart governance, smart mobility, smart environment, and smart living. Building upon, enriching, and extending the work of Giffinger et al. [9], Nam and Pardo [7] identified three components of a smart city as the dimensions of technology ("integration of systems, infrastructures and services mediated through enabling technologies" as "facilitator for creating a new type of innovative environment"); human (encompassing creativity, social infrastructure, and education in support of learning); and, institutional (encompassing governance, planning, and policy). Introducing critical, sustainability, and contextual dimensions, Al-Nasrawi, Adams, and El-Zaart [10] identify and evaluate "the main models to measure city smartness" and address noted deficiencies, whereby a multidimensional methodological model is advanced "that assists in evaluating the smartness level of a city while being sensitive to its context" where "sustainable and smart attributes of a city" are combined. Contributing to a research and practice perspective, Albino, Berandi, and Dangelico [11] address the definitions, dimensions, performance, and initiatives in smart cities focusing on metrics, indicators, and experiences. Drawing on practice, theory, and context, Ching and Ferreira [12] use a case study of six cities (e.g., Boston, San Francisco, Amsterdam, Stockholm, Singapore, and Rio de Janeiro), focusing on "smart efforts" in relation to four theories of cities (e.g., 'smart machines' and informated organizations, partnerships and collaboration, learning and adaptation, and investing for the future), found to be "complementary and not mutually exclusive" and to have been adopted in "various combinations of elements" by cities "according to their specific contexts", while "different approaches and partnership frameworks" emerged "depending on the nature of the initiatives". It is worth noting that all four theories involve innovation in some way. As such, Ching and Ferreira [12] indicate that their "findings suggest multi-dimensionality in being a 'smart' city" and conclude that "being 'smart' involves continual learning and feedback monitoring, for cities to remain aware and nimble", and that "city leaders and planners need to be 'smart' about being 'smart'".

When considering the challenges facing smart cities, Gil-Garcia, Zhang, and Puron-Cid [8] provide a conceptualization of smartness in government from an integrative and multi-dimensional perspective consisting of 14 dimensions, such as: citizen-engagement, creativity, innovation, integration, openness, and sustainability. In relation to "government smartness and creativity", Gil-Garcia et al. [8] observe from the research literature that, "people, education, learning, and knowledge have been identified as of central importance to cities' ability to innovate" while highlighting the notions of learning city, learning government, and "transparent learning environments" in support of citizen engagement. Additionally, Gil-Garcia et al. [8] note that "information sharing" is one of several keywords associated with the integration dimension of smartness. Indeed, information sharing is probed as a dimension of smartness by Gil-Garcia, Pardo, and De Tuya [13] in terms of the "benefits and challenges" in the context of the complex problems in megacities. Further highlighting this particular challenge, Gil-Garcia, Pardo, and Sutherland [14] explore the socio-technical nature of information sharing in the context of cross-boundary information sharing (CBIS) "among public and private sector actors". Articulating the complexities involved, Barth et al. [15] advance a conceptual framework for informational urbanism consisting of multiple components, one of which encompasses the subsystems of a smart city system; another the information behaviour of city stakeholders; and, yet another focusing on multiple problem areas, such as information and knowledge related infrastructure (e.g., digital/ubiquitous city, green and sustainable city, creative city), economy, spaces for information flows, e-government/governance, location factors, information behaviour and literacies, and labour, identity, and development issues. Historically, Barth et al. [15] draw on earlier work by Stock [16], providing a justification for the informational approach. Stock's work is dependent, in turn, on work by Castell [17] pertaining to the information city. In terms of implementation and practice, Mainka [18] provides an application of the theory advanced by Barth et al. [15] through the analysis of smart city developments in over 30 cities around the world. Focusing on open innovation, Paskaleva and Cooper [19] advance a multi-dimensional assessment strategy for the evaluation of Internet-enabled smart city public services, using "a novel Co-evaluation framework". Looking at seemingly intractable issues, Alavi et al. [20] point to the challenges that are associated with an Internet of Things-enabled smart city from a socio-technical perspective, highlighting concerns with privacy, participatory sensing, to name a few as well as profound changes for "human habits and physical well-being". From an integrating perspective, Yigitcanlar et al. [21] advance a multi-dimensional framework for smart cities in an effort to provide a "comprehensive understanding" of "how the complex nature of the drivers" (e.g., community, technology, policy) "are linked to desired outcomes" (e.g., productivity and innovation, sustainability, accessibility, wellbeing, livability, governance, and planning). On a practical level, Alavi and Bahrami [22] focus on "walking and its multidimensionality" in order to highlight the smart city challenges of "data and automation". In terms of an overview and future directions, Gupta, Chauhan, and Jaiswal [23] provide a classification of smart city research based on a review of the research literature where innovation is identified as one of many themes that are discussed in terms of a future research agenda. Again, on a practical level, Panori, Kakderi, and Tsarchopoulos [24] provide a smart city ontology application for measuring poverty multi-dimensionally. Extending understandings of the urban, Kar et al. [25] look beyond smart cities to digital or smart nations involving "social innovation initiatives" and sustainability. Considering the digital, O'Hara and Hall [26] explore a variety of "models and approaches to Internet governance" in the form of four visions of Internets, given the relevance of the future Internet to smart cities [2–4].

What might appear to be advantages or disadvantages of any given perspective, when considered together, a progression of thinking emerges over time where researchers influence each other, inform practice, and practitioners inform researchers. Viewed on a continuum, advantages and disadvantages of research perspectives on dimensionalities of smart cities become more dynamic, as depicted in Figure 2.

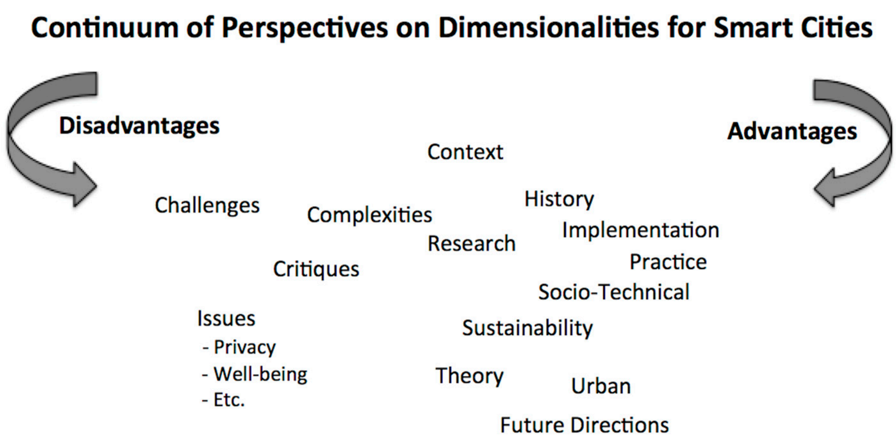

Figure 2. Advantages and disadvantages: continuum of perspectives on dimensionalities for smart cities.

2.1.2. Summary and Overview of Dimensions and Multi-Dimensionalities in Smart Cities

Table 1 provides an overview of the literature review organized by year (from 1989 to 2020), and then author and associated dimensions and multi-dimensionalities.

Table 1. Smart city dimensions and multi-dimensionalities by year, author.

Author	Year	Dimensions	Multi-Dimensionality
Castell	1989	Information city	
Giffinger et al.	2007	Classical approach to smart cities	
Nam & Pardo	2011	Technology, People, Institutions	Smart city components
Stock	2011	Informational approach	
Al-Nasrawi et al.	2015	Sustainability	Smartness, Innovation
Albino et al.	2015	Multiple	Smart—Metrics etc.
Ching & Ferreira	2015	ICTs, Inform	Smart, Data
Gil-Garcia et al.	2016	Innovation, Openness, Sustainability	Smartness/government
Gil-Garcia et al.	2016		C-B Information Sharing
Barth et al.	2017	Informational urbanism	
Alavi et al.	2018	Socio-technical	Habits, Well-being, Privacy
Mainka	2018	Analysis of smart city developments	
Paskaleva & Cooper	2018		Open Innovation
Yigitcanlar et al.	2018	Driver/outcome	Framework-SC drivers
Alavi & Bahrami	2019	Data and automation	Walking and data
Gil-Garcia et al.	2019		Information Sharing
Gupta et al.	2019		Classification—SC research
Panori et al.	2019		Poverty; Ontology SC apps
O'Hara & Hall	2020	Digital—Internet Visions	

Castell [17] advanced the dimension of information city, while Giffinger et al. [9] provided a classical approach encompassing multiple dimensions of the smart city. Nam and Pardo [7] identify multiple dimensions for smart cities, organized under technology, human, and institutional as being indicative of the multi-dimensionality of the components of a smart city. Where Stock [16] advanced an informational approach, Al-Nasrawi et al. [10] point to multiple dimensions of smart cities focusing on the multi-dimensionality of smartness and innovation through the consideration of sustainability. Albino et al. [11] highlight the multiple dimensions of smart cities focusing on smart, metrics, and other indicators to reveal the multi-dimensionality involved. Ching and Ferreira [12] identify the importance of leveraging ICTs to inform and support organizational structures and processes for decision-making and for continual learning. Gil-Garcia et al. [8] articulate fourteen dimensions in conceptualizing smartness in government from an integrative and multi-dimensional perspective, including innovation, openness, and sustainability. It is worth noting that Gil-Garcia et al. [8] point to the importance of creativity for innovation where learning is central to innovation and it is described as two-way and interactive. Barth et al. [15] provide a framework for informational urbanism with smart city components, while Alavi et al. [20] identify challenges that are associated with an IoT-enabled smart city from a socio-technical perspective. Mainka [18] employs the theory by Barth et al. [15] in the analysis of smart city components and Paskaleva and Cooper [19] use a multi-dimensional assessment strategy for evaluating Internet-enabled smart city services. Yigitcanlar et al. [21] identify the importance of "intertwining" smart city drivers and desired outcomes in support of a multi-dimensional smart city framework. Alavi and Bahrami [22] highlight the multi-dimensionality of walking in the city in relation to data and automation. Gupta et al. [23] develop a classification system for smart city research, while Panori et al. [24] focus on the multi-dimensionality of poverty in smart cities. O'Hara and Hall [26] focus on the digital in relation to several visions for the Internet.

2.1.3. Emerging and Evolving Interactions in Smart Cities

Researchers variously characterize merging and evolving interactions in smart cities as creative, social, and complex, to name a few. Florida [27] advanced the notion of the creative potential of everyone, the idea of collective creativity, and argues that "creativity requires diversity" and open-mindedness, drawing on the capacities of all. Nam and Pardo [7] claimed that, "usage of 'smart' captures innovative and transformative changes driven by new technologies" with "social factors" as "central to smart cities" where "people and how they interact" matters. Van Waart [28] speaks of designing meaningful interactions in public spaces through interactive media in smart cities. Alavi and Bahrami [22] argue that "future cities that incorporate ambient intelligence and interaction" give rise to the need to "be able to respond to the complexity of humans' interactive experiences, with and within their environments".

Highlighting a range of issues, Streitz [29] addresses the "challenges for designing interaction in future smart environments" as the computer disappears into the background and environments are more generally infused with technologies, in support of "a migration path from explicit to implicit interfaces" and interactions. McMillan [30] identifies design, accountability, and privacy issues associated with implicit interactions enabled through machine learning and predictive algorithms. Streitz [31] articulates the notion of citizen-environment interaction (CEI) in support of "cooperative cities and societies" in relation to "smart materials", "smart ecosystems", and "cooperative buildings and their extension to smart urban environments". On a practical level, Margetis et al. [32] present "InPrinted" as "a systematic and generic framework supporting physical paper augmentation and user interaction" in smart environments, focusing on interactive maps. Stephanidis et al. [1] identify interactions as "considerably escalated" in relation to "users' location, posture, emotions, habits, and intentions" as "candidate input data to a variety of visible and invisible technological artifacts embedded in the environment".

Focusing on the emergent in real time, Brown and Grinter [33] "establish the notion of designing for transient use" in the context of developing systems "to scaffold communication for short-term use by resettling refugees". Streitz [34] discusses interactions in "current and future urban environments", with a focus on the "hubs and transient spaces" of public spaces using the example of airports. In this context, Streitz [34] describes transient spaces as "spaces that are designed to accommodate a degree of mobility of people passing-through or by staying in such a space for a limited period of time", where "special design considerations" are required. Advancing the notion of people as a kind of infrastructure, Alavi and Bahrami [22] describe public space as "the corporeal space and social scene of the city" and as "the pedestrian realm, where interaction is mostly about spontaneous body management". Also described as "a public good", Alavi and Bahrami [22] claim that, "pedestrians produce the public space of the city as they walk through it and as they benefit from the pleasure of being in the crowd". Picking up on the notion of transient interactions, Alavi and Bahrami [22] note that, "the production of public space entails the diverse and inclusive participation of those who passingly inhabit it". Alavi and Bahrami [22] claim that "anonymity as an essential characteristic of urban public spaces is correlated with and embedded in their spatial configuration and the social construct", arguing that "citizen-actors become themselves the main infrastructure of the city".

2.1.4. Summary and Overview of Multi-Dimensionalities and Innovation and Interactions in Smart Cities

Table 2 provides an overview of the literature review for multi-dimensionalities, innovation, and interactions, being organized by year (from 2005 to 2019). Florida [27] calls for creativity involving everyone and the associated mindset of openness. Streitz [29] argues for a movement from human-computer interaction to that of human-environment interaction by designing for "new forms of interaction" for "future smart environments". Nam and Pardo [7] capture the multidimensionality of the smart city through identification of the components, where the element of 'smart' "captures innovative and transformative changes driven by technologies" with "social factors" as "central to smart cities" giving rise to the need for a "socio-technical view on smart city".

Table 2. Smart city multi-dimensionalities and innovation and interactions by year, author.

Author	Year	Multi-Dimensionality	Innovation	Interactions
Florida	2005	Openness	Creativity	Diversity
Streitz	2007			Designing
Nam & Pardo	2011	Smart city components	Smart as innovative	
Van Waart	2014			Meaningful
Al-Nasrawi et al.	2015	Assessment model	Sustainable + Smart	
Ching & Ferreira	2015	Smart, Data, Learning	Structure/process	
Brown & Grinter	2016			Transient
Gil-Garcia et al.	2016	Smartness/government	Smartness	Citizen centricity
McMillan	2017			Implicit
Streitz	2007			Implicit
Streitz	2018			Transient
Alavi & Bahrami	2019	Walking		Data
Yigicanlar et al.	2018	Framework-SC drivers	& Productivity	
Gupta et al.	2019	Classification	& Technology	Citizen engagement
Kar et al.	2019	Impacts	Social	
Margetis et al.	2019			Novel
Stephanidis et al.	2019			Implicit, Transient

Van Waart [28] emphasizes the importance of meaningful interactions, while Al-Nasrawi et al. [10], attentive to innovation in the literature, proposes a multi-dimensional methodological model for assessing smart city sustainability, whereby the model "assists in evaluating the smartness level of a city while being sensitive to its context". Ching and Ferreira [12] highlight the dimensions of being "smart" with the potential for information and communication technologies (ICTs) to be used to "informate" with data generated that can "innovate organizational structures and processes". Continual learning, identified by Ching and Ferreira [12], is another dimension of smart, enabling "cities to remain aware and nimble". Brown and Grinter [33] describe "designing for transient use" involving 'human in the loop' interpretation "to scaffold communication" in the short term in support of refugee resettlement interactions. Gil-Garcia et al. [8] provide a conceptualization of the multi-dimensionality of smartness in government consisting of 14 dimensions, one of which is innovation and another being that of citizen centricity and the importance of interactions. McMillan [30] provides a discussion of the challenges that are associated with design, accountability, and privacy associated with implicit interactions based on machine learning algorithms. Streitz [29] discusses the movement from explicit to implicit interaction interfaces in smart environments. More recently, Streitz [31] described environments, such as airports, in terms of transient spaces for interaction and design. Alavi and Bahrami [22] articulate the multi-dimensional nature of walking in the city where the data generated by people and their interactions forms an urban infrastructure. Yigitcanlar et al. [21] advance a framework for multi-dimensionality with smart city (SC) drivers and outcomes where innovation and productivity are the key outcomes. Gupta et al. [23] provide a classification of smart cities based on the research literature where innovation and technology are key themes along with the engaging of citizens in design. Kar [25] focus on multi-dimensional impacts, social innovation initiatives, and sustainability, while Margetis et al. [31] describe novel interactions in terms of the physical and digital in the form of "natural multimodal user interaction with any kind of printed matter in smart environments". Additionally, Stephanidis et al. [1] provide an overview of challenges associated with implicit, novel, escalated, and transient interactions "in the physical and digital continuum" in smart environments.

Figure 2 depicts the dynamic nature of the research perspectives on dimensionalities for smart cities on a continuum of disadvantages and advantages; this type of continuum also exists for emerging and evolving interactions in smart cities.

2.2. HSEI Framework for the Multi-Dimensionality of Smartness in Smart Cities

A review of the research literature focusing on the dimensions and multi-dimensionalities of smart cities and interactions enables the formulation of a conceptual framework for human-smart environment interactions (HSEI), as depicted in Figure 3. Through the dynamic of people–technologies–cities, HSEI in the form of the multi-dimensional construct of smartness, involving relationships between selected dimensions (e.g., openness and innovation, innovation and sharing, etc.) are explored. An exploration of the dimensions of smartness in terms of relationships also contributes to learning as well as opportunities for engagement with initiatives in support of urban data intervention potentials.

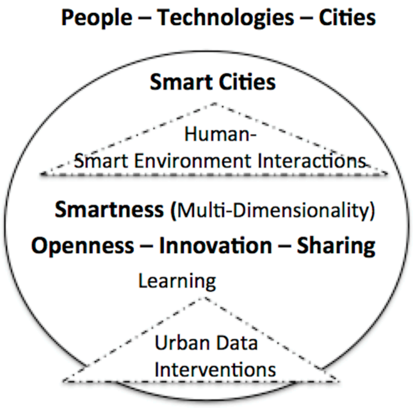

Figure 3. Human-smart environment interactions (HSEI) conceptual framework for smartness and dimensional relationships in smart cities.

For the purposes of this work, openness encompasses the definition provided by Gil-Garcia et al. [8] as "more transparent and more accountable", contributing to "a smarter government" benefitting "citizens, businesses, and other stakeholders", while being able to "use diverse information in smarter ways". In relation to data, Stephanidis et al. [1] note that open data in a smart city context enable the notion by Streitz [34] of a city being 'self-aware' of "states and processes" and able to make such data available "in a reciprocal way to the citizens" intersecting with the idea of "civic computing" by Konomi et al. [35] where people "are encouraged to provide data to the cities' data pool". Yet, Gil-Garcia, Pardo, and Sutherland [13] address the challenges associated with "cross-boundary information sharing (CBIS)" in public-private relationships in "the regulatory context" as distinct from partnerships, where "the nuances of data integration" need to be considered along with the interoperability for technical infrastructures, and the nature and implications of trust. Florida [27] includes the notion of open-mindedness in support of creative potential involving people. Gil-Garcia et al. [8] refer to creativity as involving learning, which is key to innovation, and learning that is two-way, as in, interactive. Indeed, the study of innovation and citizen-centricity in urban contexts emerges in the work of Hartmann [36] through citizen participation in the form of Hackathons. As a dimension of smartness, Gil-Garcia, Pardo, and De Tuya [14] explore information sharing in the context of "smart city initiatives" in megacities, seeking to understand benefits and challenges, where "financial resources and technical skills" do not figure strongly, as in the case of smaller cities. Gil-Garcia et al. [14] define smartness from a multidimensional and sociotechnical perspective, while information sharing is said to be "a dimension of smartness" that "allows for better communication, response, coordination, and service provision for citizens" contributing to the notion of "smarter government" [8]. Bris [37] claims that "large cities and megacities find it difficult to become smart" arguing in their work [38] that "the real test" is "whether citizens feel the benefits".

The research question in this work is reformulated as a proposition under exploration, as follows.

Proposition 1. *Relationships between selected dimensions of smartness in urban human-smart environment interactions matter for—openness and innovation; openness and citizen engagement; innovation and citizen engagement; innovation and sustainability, etc.—contributing to ways for learning about and understanding the multi-dimensionalities of smart cities, their interdependencies, and urban data intervention potentials.*

What follows is an exploration of the proposition under study in this work.

2.3. Aim and Principal Conclusions

The main aim of this work is to explore the relationships and patterns between dimensions of the multi-dimensional construct of smartness in the smart cities domain. Specifically, the dimensions of *openness* and *innovation* are explored, where, *urbanizing*, as in, adapting for urban uses, serves as a proxy for innovation. *Openness* and *innovation* are then explored in relation to *citizen engagement*, where *interactive public spaces* serve as a proxy for *citizen engagement*. Additionally, the dimension of *technology services* is explored, as is *sustainability*, where *livability* serves as a proxy. *Integration* is explored using the proxy of *sharing*, in relation to innovation.

The multi-dimensionality of smartness is explored in terms of the relationships between dimensions, in support of learning about smart cities and initiatives, such as urban data intervention potentials, as depicted in Figure 4.

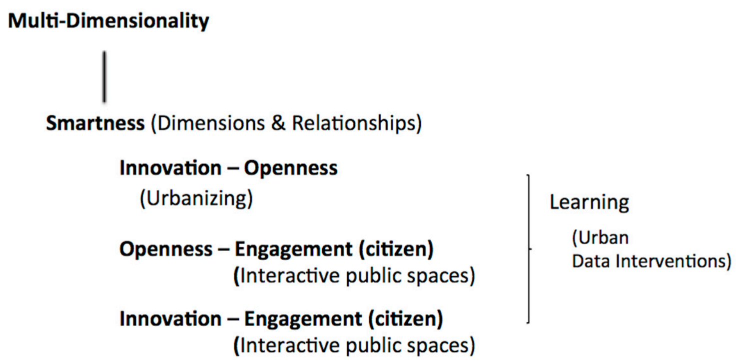

Figure 4. Smartness multi-dimensionality: dimensions and relationships for learning in smart cities.

As such, the principal conclusions of this work point to the importance of learning about the relationships between the dimensions of smart city components, such as smartness and the interplay between openness and innovation; openness and citizen engagement; innovation and sustainability; innovation and integration (sharing); and, innovation and technology services, to name a few.

3. Methodology—Materials and Methods

This paper employs an exploratory case study approach, said by Yin [39] to be particularly appropriate for investigating contemporary phenomena, in this case, the evolving multidimensionality of smartness and the relationship between dimensions in emergent smart cities. An explanatory correlational design [40] for understanding more about the relationships between several selected dimensions of smartness in contemporary urban environments is also employed in this work. Yin [39] highlights the "complementarity of case study and statistical research", where "case studies have been needed to examine the underlying processes that might explain a correlation".

A website was used to describe the study and invite participation. During sign up for the study, demographic data were collected, including, age range, gender, location/city, and people could self-identify in one or more categories (e.g., city official, community member, business, educator, student, etc.). Upon sign up, the participants were then invited to complete a survey with a combination of closed and open-ended questions. The survey instrument, containing 20 questions designed to enable respondents to explore and assess their city as a smart city, was pre-tested prior to use in the study. An example of a survey question exploring aspects and dimensions of smartness in technology-rich urban environments is: *City-focused social media and other aware technologies give rise to many possibilities. Rate your assessment for each on a scale of 1 (not at al) to 7 (absolutely).* A matrix of items to assess include: *Attuning to urban spaces, Collaborating, Connecting, Heightening urban sensibilities, Partnering, Sharing, Trust,* and *Urbanizing (e.g., adapting for urban uses).* Appendix A contains several questions from the survey instrument used for this study. The respondents were also invited to participate in an interview about smart cities to provide more in-depth details about their experience of smart cities. An example of an interview question is: *What does smartness look like in your city (e.g., smartphones, smart meters, urban displays/screens, sensors, drones, etc.)?* The interview protocol was also pre-tested prior to use in the study. Purposive sampling, more specifically heterogeneity sampling, was used to accommodate a broad spectrum of perspectives [41]. As such, an invitation to participate in the study was posted online (e.g., Academia.edu, ResearchGate, UrbanitiesLab), so as to attract researchers, students, educators, urban practitioners, and anyone interested in one or more dimensions of smart cities. A diverse array of individuals from cities in Canada, Europe, Israel, and the United States participated in the study. The case for this study consists of the experiences of many individuals at the urban level in multiple, small to medium to large-sized cities in multiple countries.

The analysis of quantitative data that were gathered from survey responses consisted of descriptive statistics, whereby the Real Statistics Software [42] Resource Pack add-in for Microsoft Excel was used, consisting of a range of supplemental statistical functions and data analysis tools, such as the correlation feature for determining the nature of the relationship between items. Content analysis, pattern matching, and explanation building were used in an ongoing and iterative fashion in the analysis of qualitative data from interviews and open-ended survey questions. In parallel with this study, qualitative data were also gathered through group and individual discussions, which were guided by the interview protocol, with a wide range of people in multiple small- to medium- to large-sized Canadian cities. Overall, across surveys, interviews, and group and individual discussions, this work is based on an analysis of data for n = 76 consisting of 41% females and 59% males for people ranging in age from their 20s to 70s. So far, two iterations of this study have been conducted, resulting in a significantly revised and a retested version of the survey instrument, based on participant feedback and the evolution of smart cities, such that the current survey sample size is very low.

4. Results

This section provides a description of results for correlating dimensions of smartness and an interpretation of results aided by a qualitative data analysis perspective.

4.1. Description of Results for Correlating Dimensions of Smartness

In the survey for this study (Appendix A), the participants were asked to assess the extent to which they associate smart cities with *openness* on a seven-point scale with 1 = Not at all and 7 = Absolutely. Responses occur at 4 on the neutral position of the scale with 25%, 25% toward the upper end of the scale at 6, and 50% at position 7, as shown in Table 3. Using *urbanizing*, as in, adapting for urban uses, as a proxy for *innovation*, 75% responded at position 5 and 25% at position 7 on the scale.

Using the Real Statistics Software [42] Resource Pack add-in for Microsoft Excel, the correlation feature is used for determining the nature of the relationship between *openness* and *innovation* (using *urbanizing* as a proxy for *innovation*) in smart cities. For this ordinal data, the result shows a Spearman correlation coefficient of .54 and it is worth noting the guidance by Creswell [40], where correlations in the .35 to .65 range "are useful for limited prediction". Akoglu [43] provides a comparative interpretation of correlation coefficients from psychology, political, and medical perspectives, indicating that a .54 correlation is interpreted as "moderate", "strong", and "fair", respectively. A scatter plot diagram of the data shows the direction of the correlation to be positive.

Openness is then explored in relation to *citizen engagement* using *interactive public spaces* as a proxy with 25% of responses occurring at position 5 on the scale and 75% at position 7. The Spearman correlation coefficient for *openness* and *citizen engagement*, using *interactive public spaces* as a proxy is .81 and, according to Creswell [40], is "very good" and "good prediction can result from one variable to the other" for correlations between .66 and .85. Akoglu's [43] comparative interpretation of a .81 correlation from multiple perspectives indicates a "strong", "very strong", and "very strong", respectively.

Table 3. Responses and correlations for selected dimensions of smartness.

Dimensions	Responses	Correlation
Openness Innovation (Urbanizing)	25% (4); 25% (6); 50% (7) 75% (5); 25% (7)	*.54*
Openness Citizen Engagement (Interactive public spaces)	25% (4); 25% (6); 50% (7) 25% (5); 75% (7)	*.81*
Innovation (Urbanizing) Citizen Engagement (Interactive public spaces)	75% (5); 25% (7) 25% (5); 75% (7)	*.33*
Openness Citizen Engagement (Inclusiveness)	25% (4); 25% (6); 50% (7) 50% (3); 50% (7)	*.94*
Innovation (Urbanizing) Citizen Engagement (Inclusiveness)	75% (5); 25% (7) 50% (3); 50% (7)	*.57*
Innovation (Urbanizing) Sustainability (Liveability)	75% (5); 25% (7) 25% (5); 75% (7)	*.33*
Innovation (Urbanizing) Technology services (Technology driven services)	75% (5); 25% (7) 25% (6); 75% (7)	*.33*
Innovation (Urbanizing) Integration (Sharing)	75% (5); 25% (7) 25% (6); 75% (7)	*.33*

Citizen engagement using *interactive public spaces* as a proxy is then explored in relation to *innovation* with 25% of responses occurring at position 5 on the scale and 75% at position 7. The Spearman correlation coefficient for *innovation* and *citizen engagement*, while using *interactive public spaces* as a proxy is .33. According to Creswell [40], "when correlations range from .20 to .35, there is only a slight relationship", such that "this relationship may be slightly statistically significant for 100 or more participants", while "this size of coefficient may be valuable to explore the interconnection of variables but of little value in prediction studies". Akoglu's [43] comparative interpretation of a .33 correlation from multiple perspectives indicates a "weak", "moderate", and "fair", respectively.

Changing the proxy for *citizen engagement* to *inclusiveness*, the relationship is explored between *openness* and *citizen engagement*, with respondents indicating 50% at position 3 on the scale and 50% at position 7. The resulting Spearman correlation is .94 and Creswell [40] suggests that correlations in the .86 and above range are "typically achieved for studies of construct validity or test-retest reliability" noting that "when two or more variables are related, correlations this high are seldom achieved", such that when this occurs, "then two variables measure the same underlying trait and should probably be combined in data analysis". Akoglu's [43] comparative interpretation of a .94 correlation from multiple perspectives indicates a "strong", "very strong", and "very strong", respectively. The relationship is explored between *innovation* and *citizen engagement* using *inclusiveness* as a proxy, with respondents indicating 50% at position 3 on the scale and 50% at position 7. The resulting Spearman correlation of .57 is, according to Creswell [40], "useful for limited prediction", while Akoglu's [43] comparative interpretation of a correlation from multiple perspectives indicates a "moderate", "strong", and "fair", respectively.

Sustainability using *livability* as a proxy is then explored in relation to *innovation* with 25% at position 5 on the scale and 75% at position 7, resulting in a Spearman correlation of .33. Similarly, *innovation* is explored in relation to *technology services* using *technology-driven services* as a proxy with

25% at position 5 on the scale and 75% at position 7, resulting in a Spearman correlation of .33. Finally, *innovation* is explored in relation to *integration* using *sharing* as a proxy with 25% at position 5 on the scale and 75% at position 7, resulting in a Spearman correlation of .33.

Walkability, although not part of the 14 dimensions of smartness, could be construed as a proxy for *citizen-centricity.* When explored in relation to *innovation*, *walkability* as a proxy for *citizen-centricity* shows a response of 25% at position 5, 50% at position 6, and 25% at position 7 on the scale, for a "very good" [40] correlation of .81, as depicted in Table 4.

Table 4. Responses and correlation for innovation and citizen-centricity as dimensions of smartness.

Dimensions	Responses	Correlation
Innovation (Urbanizing) Citizen-Centricity (Walkability)	75% (5); 25% (7) 25% (5); 50% (6); 25% (7)	.81

What follows is a discussion and interpretation of results, aided by the use of qualitative data from open-ended survey questions, in-depth interviews, and group and individual discussions.

4.2. Interpretation of Results Aided by a Qualitative Data Perspective

Smartness and Interactivity. When asked, "what does smartness look like in your city?", one participant responded, "smartness in this city is increasing from a smart phone perspective and apps available, but we do not see too many physical manifestations of this yet", although "I just noticed a bike counter the other day, down by the Railyards" development. An educator pointed to the potential for making such urban elements more interactive, where, through an urban display, people could be invited to respond to questions such as "how can we improve?" or "where are you from?" Another participant commented that "smart also needs to be synonymous with social, useful, and having clear purpose", while another observed that "the gatherings created from various festivals often result in temporary urban interventions". Another suggested use of the term "wise city" encouraging the notion of "friendly, comfortable that reflects human values and needs", such as "freedom and openness".

Interactive Public Spaces. It is worth noting that, from a city and business perspective, one individual highlighted the need to "make involvement as intuitive and frictionless as possible". Looking more closely at the correlation results in relation to the qualitative data emerging form open-ended survey responses and in-depth interviews, in the context of *interactive public spaces*, in terms of smart city initiatives and interventions involving data generation potentials, it is worth noting the response of a city information technology (IT) manager in relation to the use of data analytics, who commented that "we're starting to look at the tools to help us mine the data that we already have an interest in" and "beyond that, we're very much immature in that overall data sense". Going forward, with more education, funding, and resource support, the *interactive public spaces* element could improve and this may in turn affect the correlation.

Citizen-Centricity. Regarding notions of *citizen-centricity*, walkability, together with the development and placement of urban elements emerged in relation to a fountain in an urban roundabout that was highlighted by an educator, because "they could orchestrate it with color and sound" and other features and, as such, was described as a "touchstone", in that "it brought people out" and "it made an awareness of something in the community" and "it was fun". The educator also observed that the fountain "made people talk" to each other and "it slowed people down". From a city and business perspective, one individual commented that, "smart cities are those that are citizen-centric and inclusiveness-minded", where "technology is a tool to be mapped on top of excellent strategy, planning, approaches, and civic understanding", with "efforts focused around people and their needs, with everything else playing a supporting role". An educator commented that, "I'm always looking for the more visual stuff" as in, how cities present "the visual sense of the city". Referring to city dashboard information, a student noted that "you can take this kind of data and rather than just present numbers you can make beautiful artistic visualizations", adding that "this is how to get people on board". In response to the question, "what other key elements contribute to your idea of a smart city?" a community leader/member identified the need for "finding fun and meaningful ways to engage the public" in order to "visualize this data", so as to "simplify it for the larger public".

Sharing. In terms of learning about the potential associated with urban data, City IT commented on "that hurdle of just really starting to educate" about "what could be done" and "educating ourselves" in that, "we haven't had any kind of funding to do these things". Indeed, the potential for learning and engagement is articulated through the example of an eTownHall meeting featuring the notion of "documented engagement" with data being generated live through social media and other tools with the potential to be acted upon for decision making and other purposes. The notion of learning as continuous emerges, whereby an educator noted that it becomes "a subsumed part of what you are doing everyday, all the time" as in, "you are all learning all the time, you're sharing knowledge". Individuals involved with placemaking [44] and community engagement expressed interest in opportunities for temporary data interventions to learn more about urban patterns and the use of urban elements such as the idea of a "smart bench", while city IT commented that "fundamentally there is a desire to be very, very open with public data" while adhering to "privacy regulations" and being cognizant of "the public's preferences". Again, going forward, with more education, funding, and resource support, the *integration and information sharing* element could improve and this might, in turn, affect the correlation. As such, the findings in this work would seem to support the proposition that *relationships between dimensions of smartness in human-smart environment interactions matter, contributing to ways for learning about and understanding the multi-dimensionalities of smart cities, their interdependencies, and urban data intervention potentials.*

5. Discussion

Using *inclusiveness* as a proxy for *citizen engagement* instead of *interactive public spaces* resulted in a "good correlation" of .81 [40] when correlated with *openness,* suggestive possibly of a broader approach to taking people and their voices into consideration in designing smart environments. Additionally, the varying results for *citizen engagement* proxies when correlated with *openness*, and then with *innovation*, highlight the complex nature of the relationships involved in multi-dimensional aspects of smart cities, such as smartness. Taking into consideration work that was completed by Alavi and Bahrami [22] on the multi-dimensionality of walking, *walkability* would seem to provide a promising avenue of study for smart cities and for human-smart environment interactions (HSEI), encompassing the potential for engaging more meaningfully with data, learning about data in smart environments, and shedding light on emerging understandings of implicit interactions [28,30] and transient interactions and spaces [33,34]. Correlations for *citizen engagement* in this work using *interactive public spaces* as a proxy and then *inclusiveness* as a proxy in relation to *openness* and *innovation* suggest the importance of exploring the interweaving of smart city elements and possibly novel combinations of elements in learning more about optimizing HSEI. Explorations of *sustainability* using *livability* as a proxy, may contribute to a HSEI perspective for the study and practice of future cities going forward. Qualitative findings pertaining to learning as ongoing and continuous in everyday environments seem to support the notion by Ching and Ferreira [12] of the need for continual learning in smart cities. This work would also seem to support and shed further light on the need advanced by Streitz [34] for keeping people in the loop in smart city developments, initiatives, and interventions and, in meaningful ways. Additionally, correlations provided in this work serve to support the multi-dimensionality of the smartness [8] construct based on the definition of multi-dimensionality that was provided by Wong, Law, and Huang [5], as having "a number of interrelated attributes or dimensions". Correlations of .33 emerged for *innovation* in relation to the dimensions of *sustainability (liveability)*, *technology services (technology driven services)*, and *integration (sharing),* indicative of low prediction potential. It could be argued that the small survey sample size, together with the early-stage smart city contexts, might be reflected in these correlations, such that a change in the correlations might occur over time as this study is extended further and as cities become more involved in smart cities development. Further, the high correlation of .94 for *openness* and *citizen engagement* (*inclusiveness*), suggests that further work will be needed to find other more appropriate dimensions, as demonstrated by the use of *inclusiveness* as a proxy for *citizen engagement* when compared with that of *interactive public spaces*.

5.1. Findings and Implications

The findings and their implications are considered in this work in terms of both practice and research, going forward.

(a) **Future Practice Directions.** Involving people more meaningfully and purposefully in smart city planning and development is featured in this work, going beyond the perfunctory ‘public consultation’ that “ticks all the boxes” in the words of one community leader, in meeting the necessary requirements. For example, illustrating the relationships or correlations and interdependencies between walkability, liveablity, and innovation in learning more about the nature and value of data in urban environments emerges, giving rise to the need for translating interactivtiy data into meaningful visualizations and other types of renderings, building on work by Batty, Hudson-Smith, Hugel, and Roumpani [45] to aid in understanding, decision-making, and the like. In turn, with increased understanding, the rationale is strenthened for the opening of spaces for practical exploration, funding, and policy development as capacity building mechanisms for smart cities going forward.

(b) **Future Research Directions.** While the correlations that emerged in this work appear to vary considerably from .33 to .94, it is worth noting that correlations in the .35 to .65 range are said by Creswell [40] to be “the typical values used to identify variable membership in the statistical procedure of factor analysis”. As such, relationships between dimensions of smartness, such as openness and innovation (using urbanizing as a proxy) and innovation and citizen engagement (using inclusiveness as a proxy), give rise to avenues for further and more detailed analysis going forward. The potential also exists to extend the analysis of correlations to other dimensions of smartness (e.g., equality). Where proxies are used in this study for the correlation of dimensions, such as innovation, the use of innovation, more directly could be used in future studies.

5.2. Limitations and Mitigations

A key limitation of this work is the small survey sample size and this is mitigated by the potential to extend this work to include individuals in other cities, regions, and megacities. From a statistical perspective, although the number of participants in this study is too small to generalize an approach to smart city analysis, and while one of the limitations of the case study approach is considered to be the small possibility for the generalization of the results, Lee and Baskerville [46] point to the possibility for analytic generalizations of case study findings to theory, in this case urban theory. Another limitation of this study might be the use of proxies for assessing relationships between dimensions of smartness (e.g., urbanizing as a proxy for innovation) and this could be mitigated going forward through the use of more direct assessments.

6. Conclusions

This work provides the correlating of selected dimensions of smartness based on case study findings through an exploration of the dimensions and multi-dimensionalities of smart cities. This work supports, for the most part, the proposition under exploration that relationships between selected dimensions of smartness in urban human-smart environment interactions matter, depending upon the correlation. Such relationships also matter in seeking to open new spaces in support of involving people more directly, meaningfully, and purposefully in the design, planning, and development of smart urban environments and regions.

This work expands upon the notion of human-environment interactions (HEI) [1] by conceptualizing the human-smart environment interactions (HSEI) framework in smart cities. The framework is then operationalized for use in this work in taking people and their experiences and assessments more meaningfully into consideration. As such, a key contribution of this work is the development of a *human-smart environment interactions (HSEI) conceptual framework for smartness and dimensional relationships in smart cities* with implications for innovation and learning pertaining to urban interactions and associated intervention potentials. Conclusions that can be drawn from this study identify the presence of relationships among dimensions of smartness in smart cities, shedding light on why such relationships matter. For example, the "very good" correlation that was achieved between *openness* and *citizen engagement* using *interactive public spaces* as a proxy is promising for further explorations of data generation potentials in such spaces. Similarly, the "very good" correlation achieved between *innovation* using *urbanizing* as a proxy and *citizen-centricity* using *walkability* as a proxy, show promising data generation potentials for further exploration and learning. Potential also exists for investigating novel interactions in smart urban environments enabled by the Internet of Things (IoT) and other future Internet-related aware technologies by exploring additional dimensions, for example, feelings of comfort, trust, and/or safety.

The absence of adequate funding, resources, and education to support the use of data analytics tools, as identified by qualitative findings from city IT personnel, suggests that a space appears to be present for data interventions, initiatives, and other smart city projects to demonstrate potentials for value, engagement, and innovativeness. Such initiatives could provide potential applications for testing and further validation of the HSEI conceptual framework that is advanced in this work.

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Conflicts of Interest: The author declares no conflict of interest.

Appendix A

Urban Research Study—Questionnaire (Selected Questions)

1. I have read the informed consent document and:
   I am over 18 years of age and I agree to participate in this study _____

2. To what extent do you associate smart cities with each of these terms, on a scale of 1 (not at all) to 7 (absolutely)?

	Not at all	Not sure	Maybe	Neutral	Sort of	Sure	Absolutely
Compactness	___	___	___	___	___	___	___
Inclusiveness	___	___	___	___	___	___	___
Interactive public spaces	___	___	___	___	___	___	___
Livability	___	___	___	___	___	___	___
Mixed-use spaces	___	___	___	___	___	___	___
Multiple modes of transport (biking etc.)	___	___	___	___	___	___	___
Openness	___	___	___	___	___	___	___
Place-making	___	___	___	___	___	___	___
Technology-driven services	___	___	___	___	___	___	___
Walkability	___	___	___	___	___	___	___

3. What does smartness look like in your city (e.g., smartphones, smart meters, urban displays/screens, sensors, drones, etc.)? ____

4. City-focused social media and other aware technologies give rise to many possibilities. Rate your assessment for each on a scale of 1 (not at all) to 7 (absolutely).

	Not at all	Not sure	Maybe	Neutral	Sort of	Sure	Absolutely
Attuning to urban spaces	___	___	___	___	___	___	___
Collaborating	___	___	___	___	___	___	___
Connecting	___	___	___	___	___	___	___
Heightening urban sensibilities	___	___	___	___	___	___	___
Partnering	___	___	___	___	___	___	___
Sharing	___	___	___	___	___	___	___
Trust	___	___	___	___	___	___	___
Urbanizing (e.g., adapting for urban uses)	___	___	___	___	___	___	___

5. In your opinion what contributes to the making of a smart city? ______________________

6. What other key elements contribute to your idea of a smart city? ______________________

7. What other comments would you like to make about smart cities? ____________________

8. Please self-identify in one or more of the following categories.

Business	___
City Official	___
Community leader/member	___
Educator	___
Student	___
Other	___

9. What is the name of the city or urban area where you are located? __________________

10. Please indicate your age range.

18–19	___
20–29	___
30–39	___
40–49	___
50–59	___
60–69	___
70 or older	___

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