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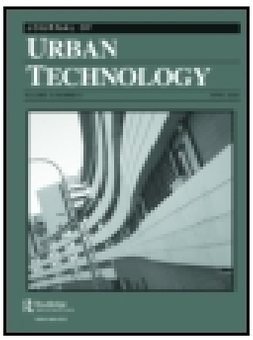

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Input-Output Modeling for Smart City Development

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ABSTRACT

While many national and local governments in the world are placing their bets on smart city development in countering challenges such as climate change, air pollution, and congestion, few know exactly how to develop them in practice. A high and rising number of publications has appeared addressing the concept of "smart city," but not many address its implementation. This paper aims at a conceptual understanding of the smart city by describing its various facets and using them to develop an Input-Output model helping policymakers and analysts make informed design choices. Using this model allows them to further their conceptual understanding of smart cities, envisage design choices they will face during planning and implementation, and help them to understand the impact of these choices. The model is illustrated by introducing the case of "Smart Dubai." Overall, this paper provides enhanced understanding of smart city development processes. This can be used in decision-making processes.

KEYWORDS

Smart city development; input-output model; design variables; Smart Dubai; implementation

Introduction

In the past decade, the popularity of using smart city labels for sustainable techno-driven urbanization has increased dramatically (de Jong et al., 2015; de Jong et al., 2018). Smart city initiatives combine a variety of ambitions reflected in the precepts for smart growth and ecological modernization, which suggest that continued economic growth is possible alongside decreased environmentally harmful output. This is achieved by steering production and consumption more towards high-tech services. This list includes city concepts like "sustainable cities," "eco cities," "low carbon cities," "knowledge cities," "information cities," "innovation cities," "intelligent cities," "digital cities," and "smart cities." In particular, the popularity of the latter has skyrocketed in the past few years. The bibliometric study by De Jong et al. (2015) into different types of future cities indicated that the use of the smart city label in the academic literature had already overtaken the previous

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champion and umbrella term of "sustainable city" by 2012. The study counted the number of times that 12 city labels were mentioned (single and plural) in the abstract, title, or keywords of academic articles or reviews until 2013 in Scopus[1]. Employing the same procedure used by De Jong et al. (2015) in their seminal work, we updated their study by including scientific articles and reviews that were published afterwards (until the end of 2018). The results are presented in Figure 1. This figure indicates that the dominant position of the "smart city" has taken on staggering proportions and has overtaken and completely eclipsed other terms. This may reflect the importance attached to it in the world of planning and policy-making.

Equally significant is the shift of the "smart city" label in its relative position vis-à-vis other future city labels in terms of its conceptual co-occurrence, as shown in Figure 2. It clearly indicates that "smart city" has driven the "sustainable city" out of the center as a city label with the highest centrality score, and has taken over its position, although smart and sustainable are still strongly interconnected.

Although the "smart city"' label has seen exponential growth in the number of publications (Komninos and Mora, 2018), and its meaning has shifted, thus far there are few indications that it has contributed in making cities actually "smarter." Despite the fact that the notion of smart city development is increasingly popular,[2] one should also notice that it has grown increasingly ambiguous for policy makers, city developers, and practitioners who are in need of more systematic and fine-grained conceptualization (Komninos and Mora, 2018). Various models have been developed to advance smart city development (Chourabi et al., 2012; Lee et al., 2013; Neirotti et al., 2014), but all are primarily descriptive in nature and offer few clues on how to flesh out smart cities in practice.

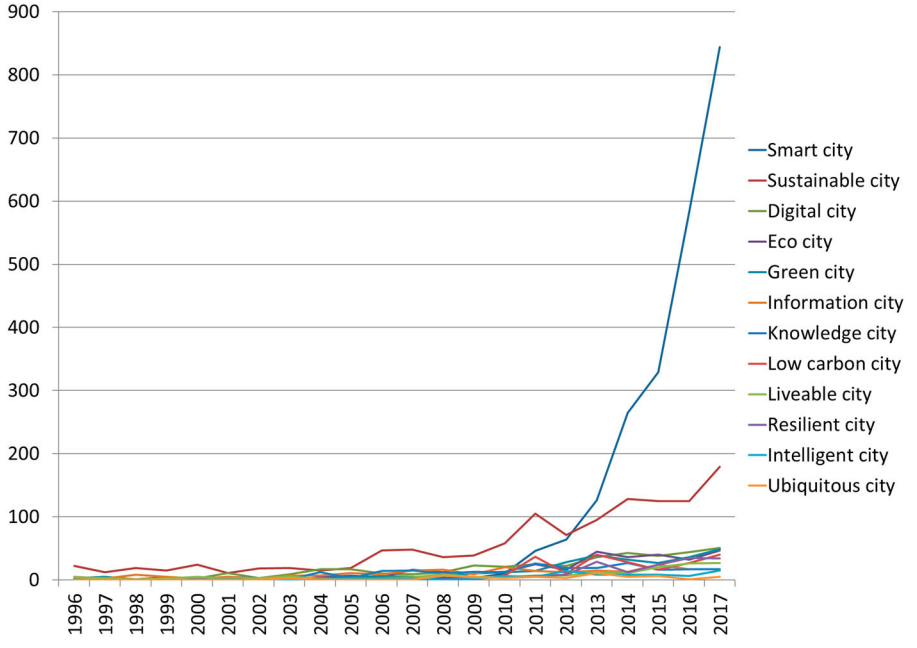

Figure 1. Frequency of appearance of different city labels over time in academic research articles (Scopus, N = 6475 articles)

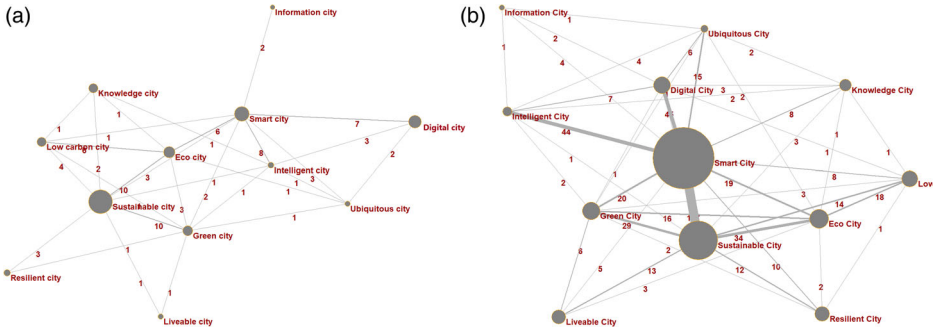

Figure 2. Network diagrams depicting co-occurrence of 12 city labels in title, abstract, and keywords in academic research articles (Scopus)

The goal of the present paper is, therefore, to map the various facets of the smart city, transform these into an Input-Output (IO) model, and provide an overview of design variables that can be handled when developing a (specific type of) smart city. The idea of IO modeling is to position and pinpoint key facets of the smart city and dynamics of smart city development (Batey and Rose, 1990). Covering all aspects of a smart city is impossible and our aim is to develop a parsimonious model that can help in making the main design decisions. The contribution of our IO model is that it allows for conducting a dynamic analysis in various domains represented within smart cities. The model makes facets of smart cities tangible and transparent, allowing decision-makers, city planners, developers, and engineers to envisage what the relevant design variables are, which choices they can make, and what their chosen type of smart city may look like in practice. The main question addressed in this paper is: How to develop a conceptual model to analyze smart city development that can also be used by policy-makers and practitioners in relevant decision-making processes? In order to answer the main research question, the following sub-questions are used:

(1) What are the key facets attributed to smart city in the academic literature?
(2) What are the key elements directly and indirectly related to smart city development? And how can they be used to develop and elaborate an IO model on smart city implementation?
(3) How can this IO model for smart city development be used?

To answer the first sub-question, we conducted a content analysis of the literature and presented our main findings in Table 1. Besides that, a bibliometric analysis was conducted to map the structural linkages between the keywords in the smart city literature. To answer the second question, an IO modeling approach was used. This is presented in the third section of this paper. IO is founded in systems theory (See Figure 3) which translates sources (input) into policy deliverables (output) and identifies the main decisions that can be made to transform inputs into outputs (Checkland, 1999).

*In order to answer the third question, we analyze*d the grey literature on smart cities and conducted interviews for the illustrative case of "Smart Dubai" and translated these findings into terms that are used in the IO model. We thus examined how the IO

Table 1. Smart city meanings and domains as used in the academic literature

Source	Meanings and Main Domains
Komninos (2008)	Use of networked infrastructures as a means to enable social, environmental, economic, and cultural development
Glaeser and Berry (2006)	Role of human capital and education in urban development
Hollands (2008)	High capacity for learning and innovation, creativity, institutions of knowledge production, and digital infrastructure for communication
Caragliu and Nijkamp (2011)	Considering the human and social capital, using ICT, sustainable economic growth, role of management
Paskaleva and Megliola (2011)	Better quality of life becoming a life-time outcome of urban functioning
Kuk and Janssen (2011)	Innovative information sharing technology, smart citizens, and businesses
Schaffers et al. (2012)	Advanced infrastructures, sustainability, economic growth, quality of life
Chourabi et al (2012)	Management and organization, technology, governance, policy, people and communities, the economy, built infrastructure, the natural environment
Anthopoulos (2015)	Resource, transportation, urban infrastructure, living, government, economy, coherency
Lee et al. (2013)	Urban openness, service innovation, partnership formations, urban pro-activeness, smart city infrastructure integration, smart city governance
IBM	Planning and management services, infrastructure services, human services
ITU (2014)	Environmental sustainability, productivity, quality of life, equity, and social inclusion, infrastructure development
UN Habitat (2014)	Productivity and the prosperity of cities, urban infrastructure, quality of life and urban prosperity, equity and the prosperity of cities, environmental sustainability, and the prosperity of cities
ISO (2014)	Economy, education, energy, environment, finance, fire and emergency response, governance, health, recreation, safety, shelter, solid waste, telecommunication and innovation, transportation, urban planning, waste water, water, and sanitation
Neirotti et al. (2014)	Natural resources and energy, transport and mobility, buildings, living, government, economy and people
Joss (2015)	Urban governance, technology infrastructure
Negro et al. (2015)	People, information, knowledge, and ICT
Yigitcanlar (2015)	Sustainability; wellbeing and livability, economy, governance
Joss et al. (2019)	Governance, infrastructure, international, digital technology, society, economy, spatial planning, innovation, environment and sustainability
Kitchin (2019)	Smart citizens, neoliberalism, technological solutionism

model could be applied and what type of smart city "Smart Dubai" can be labeled as. In principle, we could have chosen any other case for our illustration purposes, since we also had usable data for Amsterdam Smart City, Barcelona Smart City, and Masdar City in Abu

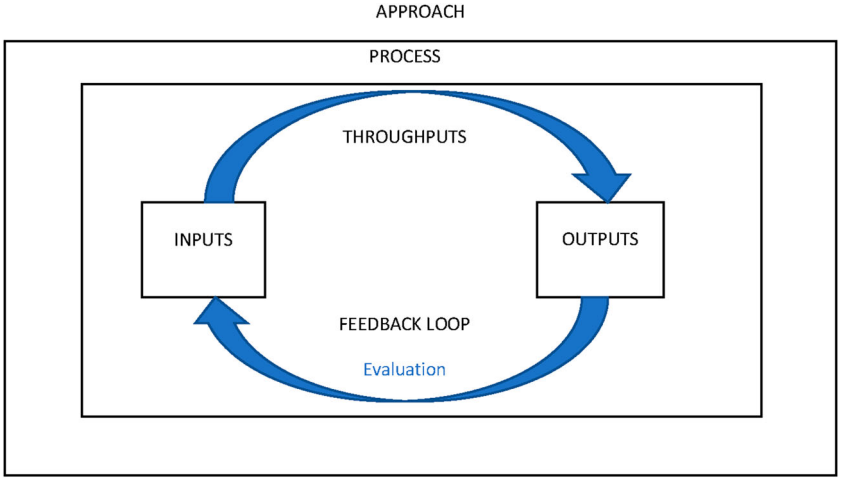

Figure 3. The IO model structure and its components (adapted from systems theory, Checkland, 1999)

Dhabi, but Smart Dubai is less often described in the literature, yet it is highly innovative. Moreover, it involves comparatively high investments, shows progressive vision, recently appears in several international rankings (i.e., the Global Smart City issued by Juniper Research, 2017; the global Smart City Discourse Network issued by Joss et al., 2019), and has adopted an intriguing governance approach making it a candidate of good practice and serving as an international benchmark (Yigitcanlar et al., 2018). The data collection for the Smart Dubai case entailed conducting interviews, collecting text documents, and making site visits. Interviews were conducted with officials and experts from public and private organizations involved in the Smart Dubai program in 2018.[3] Three of the five co-authors participated in a research trip to Dubai. Interviews were recorded on a digital audio recorder and transcribed using interpretative content analysis.

Positioning and Pinpointing Key Facets of the Smart City

Using the academic literature, we identified key attributes of smart cities in order to answer the first research question. Currently, there are multiple and various definitions of the smart city concept (Chourabi et al., 2012; Hollands, 2008; Caragliu et al., 2011; Yigitcalar, 2015). Table 1 shows that the variety of definitions and aspects attributed to it has increased substantially over the years. Moreover, the expectations that policy-makers and analysts have of smart cities also vary, making the whereabouts of its implementation hazy.

As one can see, ICT infrastructure plays a key role in some of them, but the meaning of "smart" has broadened considerably and spread out to many urban infrastructures and services and aspects of livability and sustainability leading to a great variety of ways in which "smart" can be implemented.

Figure 4 shows the results of the bibliometric analysis of key words around the smart city concept appearing in the academic literature. Internet of Things (IoT) is clearly at the center of the whole graph and tightly connected with data related concepts including big

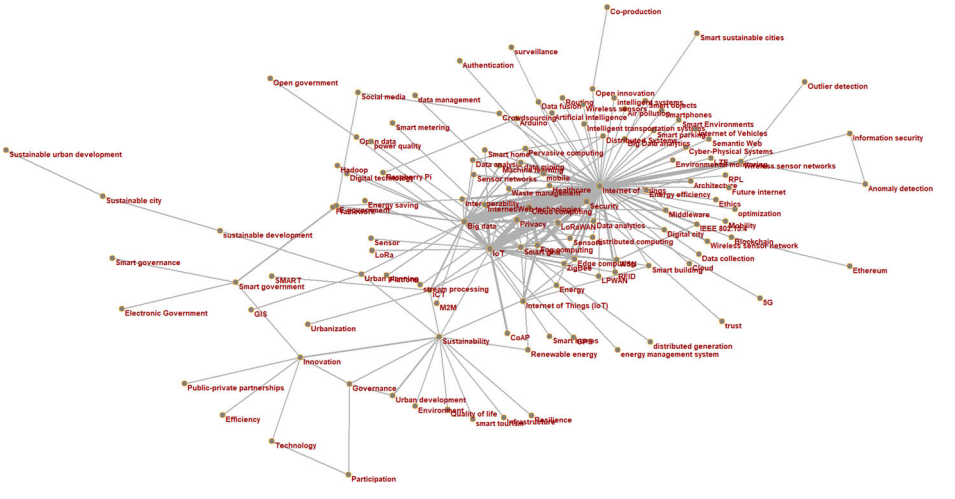

Figure 4. Structural linkages between keywords in the smart city literature, demonstrating the dominance of IoT (Publications between 1996 and 2018; N = 3573 articles)

data, data analytics, security, and privacy. Yet, it is also linked with a wide selection of concepts ranging from cloud computing, energy (i.e., renewable, smart meter, energy efficiency), and healthcare to mobility, and even ethics, trust, and social media. In the lower part of the graph, there are the governance- and sustainability-related concepts.

Another extensive study (Anthopoulos et al., 2015) concludes that there is broad agreement among experts that essentially six dimensions of the smart city can be identified: people, governance, mobility, economy, environment, and quality of life. They propose these six dimensions as facets of the smart city which can be included in developing an integrated conceptual model. However, a missing crucial element is technology. Similarly, Chourabi et al. (2012) developed an integrative framework to identify crucial factors of smart city initiatives and examine how local governments imagine possible future smart city initiatives. This framework includes eight factors: management and organization, technology, governance, policy context, people, economy infrastructure, and environment (Chourabi et al., 2012). Overall, the previous models are mainly focused on smart city facets. Inspired by these previous modelling exercises, our goal is to determine where each facet is located in the smart city development process by classifying them as inputs, throughputs, and outputs. The only model that adopted an input-process-output logic is Yigitcanlar's multidimensional smart city framework (Yigitcanlar et al., 2018). However, it still is too general for practitioners and policy-makers to pinpoint smart city facets in inputs, throughputs, and outputs.

More specifically, our proposed model consists of the following domains of the smart city based on an extensive literature review:

- **Modern ICT infrastructures and data** (Hollands, 2008; Caragliu et al., 2011; Kuk and Janssen, 2011; Steventon and Wright, 2006; Lee, 2009; Negre et al., 2015; Cianci et al., 2014; ISO, 2014; Joss et al., 2019; Kitchin, 2014);
- **Financial resources** (ISO, 2014; Neirotti et al., 2014; Chourabi et al., 2012; Florida, 2005; Lu et al., 2011; Yigitcanlar, 2014);
- **Governance** (Anthopoulos, 2015; (ISO), 2014; Neirotti et al., 2014; Lee et al., 2013; Chourabi et al., 2012; Hollands, 2008; Joss, 2015; Joss et al., 2019);
- **Human infrastructure and entrepreneurial capital** (Chourabi et al., 2012; Glaeser and Berry, 2006; Kuk and Janssen, 2011; Caragliu et al., 2011; Yigitcanlar, 2015; Munier, 2007; Mortensen and Jonsbak Rohde, 2012);
- **Smart citizens and applications** (Neirotti et al., 2014; Kuk and Janssen, 2011; Chourabi et al., 2012; Mortensen and Jonsbak Rohde, 2012; Streitz, 2011);
- **Sustainability and high quality of life** (Caragliu et al., 2011; International Telecommunications Union, 2014; UN, 2014; Paskaleva and Megliola, 2011; Schaffers et al., 2012; Yigitcanlar, 2015; Cianci et al., 2014; Munier, 2007; Yigitcanlar and Lee, 2014; Zhao, 2011).

The next step is to translate these into inputs and outputs to conceive of smart city facets for our conceptual model. When portraying the smart city as an object of urban development policy, we are convinced that it can be conceptualized as a process; we group the eight domains of the smart city mentioned above in two categories to indicate how different facets are positioned vis-à-vis each other in the smart city development process:

(1) Source-based (or need-oriented) domains refer to the needs and resources for building a smart city, such as modern ICT infrastructure, data, human infrastructure and entrepreneurial capital, governance, and financial infrastructures
(2) Target-based (or commitment-oriented) domains revolve around the results, the objects, and deliverables of smart city promises. These include smart applications and externalities.

In the following section we apply these categorized key facets to map our conceptual model of the smart city development process.

Conceptual Model

In this section we present an IO model that has been developed for a city in an institutional environment in which a local government wishes to develop (itself into) a smart city, and policy-makers draft and implement smart city development plans. The idea is that the various sorts of inputs of the smart city vary and that there is no such thing as "the" smart city, but there are various conceivable types of it. The transformation from input to output and then back is determined by two arrows: (a) a transformation process from input through throughput to output, and (b) an evaluation pathway (feedback loop) from output back to input. This flow is presented in Figure 5.

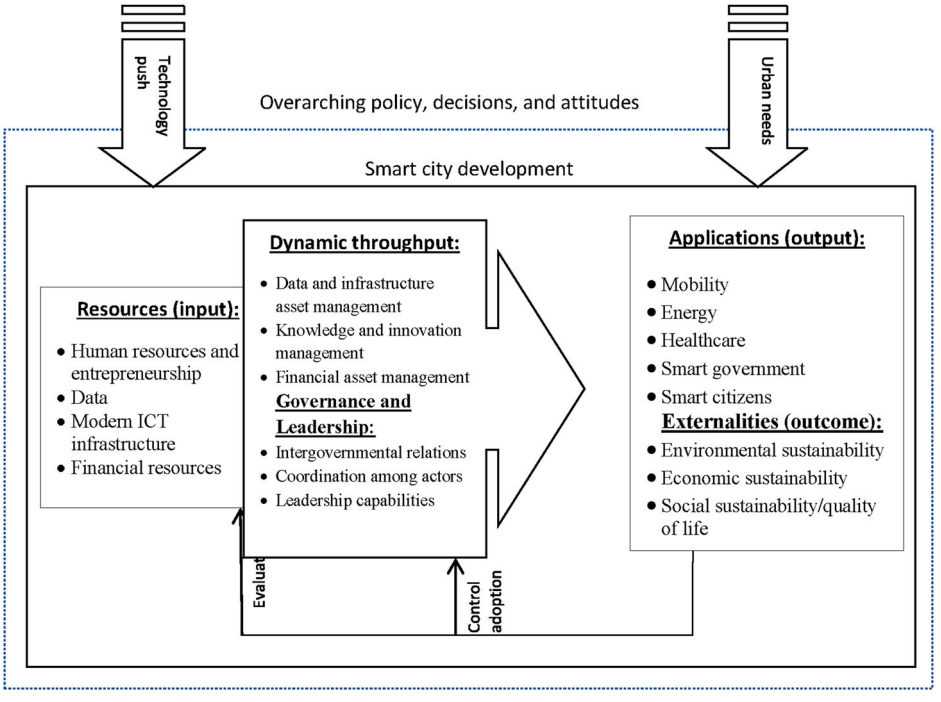

Figure 5. Graphical conceptualization of the IO model for the Smart City development process (as compiled and drawn by the authors)

Input

Input refers to the domains of the smart city for which goals are formulated and resources made available. To characterize these resource-based domains, we first define them, then pinpoint their application in smart cities, and finally sketch what potential they offer for realizing the smart city.

Modern ICT Infrastructure: Internet of Things. From an engineering point of view, a smart city is expected to deal with technology as well as the interconnection between technology and people (e.g., citizens, governments, and companies). On the one hand, there is a need for smart urbanism as an innovative solution for urban problems. On the other hand, the emergence of the IoT through technology push gives it an increasingly important role in fulfilling these expectations. As the Rothwell Innovation Model (1992) shows, the smart city can be viewed as an innovation resulting from the need to resolve urban issues and the new technology push offered to deal with them (Rothwell, 1992). Accordingly, the availability and quality of ICT infrastructures have become some of the main resources for many cities aiding them to brand themselves as "smart." Gemma (2014) mentions as examples of what ICT infrastructures can achieve: (1) ICT-enabled information and knowledge sharing; (2) ICT-enabled forecasts; and (3) ICT-enabled integration. State-of-the-art ICT infrastructures, often referred to as Internet of Things (IoT), play a crucial role in smart city development since they act as a platform for the aggregation of information and data and enable an improved understanding of how a city functions in terms of resource consumption, services, and lifestyles. Janssen and Estevez (2013) define the platform as a focal point where various types of actors interconnect in a common area. There is a wide range of possibilities for smart city development based on this state-of-the-art technology and IoT platforms. The IoT infrastructure for the smart city refers to management of the city through connecting to physical objects (through sensors, camera, RFIDs, etc.), using a large amount of real-time data (energy and environment, transportation and traffic, healthcare, safety and justice, and business), transforming data into trustworthy and reliable information and delivering the right information to the right person at the right time in the most appropriate way.

Data. In the present era, the competitive advantage is directly related to the level of access to "data and information." The higher the level of access to data, the greater ability to control and enhance the future. But this is not valid for all data; data must be processed and made useful, reliable, and manageable. Provisioning aggregated data through embedded sensors from traffic and transportation systems, buildings, energy systems, and also people, products, and companies is crucial for developing an integrated platform to communicate within the smart city. IoT provides a platform for sensors and actuator devices to communicate seamlessly within the smart city environment and enables increasingly convenient information sharing across platforms. Furthermore, the physical infrastructure of the city must be integrated into the digital and communicative infrastructure in order to increase the mobility and effectiveness of the city and the administrative systems which connect its many stakeholders. To do this, data is the linkage for making this connection. Big data, sharing data, and open data platforms are required to have

an IoT platform for real-time data accessibility. For these reasons data as an asset is another key resource in building a smart city.

Human Resources and Entrepreneurship. Human resources and entrepreneurship refer to facilities honing human resources and taking advantage of their expertise as well as the provision of facilities for entrepreneurial initiatives. These should jointly promote the generation and implementation of creative ideas driving innovation towards smart solutions.

There are three main reasons for considering human and entrepreneurial resources as a source-oriented domain of the smart city. First, although technology and particularly modern ICT are the key enablers of smart city initiatives (Chourabi et al., 2012), a smart city requires human involvement to become effective. Second, entrepreneurship is one of the main drivers for a smart economy to stimulate creativity and innovation. Finally, as Nam and Pardo (2011) stress, community commitment to the enactment and use of technology is crucial in initiating smart city initiatives. Managerial and organizational factors are also considered as important factors in smart city development (Chourabi et al., 2012). Having research centers in place to foster creativity and innovation related to the smart city, building support structures for start-ups and entrepreneurship, and establishing knowledge-sharing programs are all potentially fruitful ways to develop human and entrepreneurial infrastructures.

Financial Resources. One of the important input facets for building such a techno-driven city is financial resources which a smart city requires to build modern IoT infrastructures. Designing and equipping IoT platforms necessitates embedded sensors and actuator devices to aggregate data and then having a connectivity layer which is responsible for transmitting aggregated data and an interface between embedded sensors and the network server. Besides these, for security purposes, IoT platforms need investment in cyber security which is conducive to privacy and safety of all data within the network through providing a secure and reliable substrate for data transmission and big data storage. However, the smart city is not necessarily just ICT-based, but also deals with other aspects of innovation (Anthopoulos et al., 2015). A Research and Development budget that is typically made available by local government would also allow for fostering innovation and inventing smart solutions (Hoppe et al., 2016). In addition, some investment in branding and training practices would enable the smart city to attract more actors (e.g., experts, citizens, investors, and business firms) to commit themselves. The possible funding sources for the smart city can be funds provided exclusively by local, regional, or state governments, but may also be obtained from public and private co-funding arrangements, or even mainly private investment. Crowdfunding has also become increasingly popular among start-ups, for it offers additional financial resources (Carè et al., 2018).

Throughput

Throughput refers to the managing and organizing of resources and assets, and making decisions about how to transform them into the output to achieve intended goals and outcomes (Checkland, 1999). Throughput for smart city development allows for the modification and alignment of resources and processes within various contexts (Gupta et al.,

2015). Therefore, the process of transforming input to output (which in system theory is known as throughput) requires management, administration, and leadership skills and involves a variety of actors. Dynamic throughput refers to the ability to manage the resources and develop competencies in order to produce output (Teece et al., 1997). One of the most important smart city capabilities is the ability to turn data into value; providing reliable information in the context of smart city (Gupta et al., 2015). The ability to use and maintain data and infrastructure assets has a significant impact on delivering sensed aggregated organized data as smart applications and data visualization. Knowledge and innovation management mainly address the question how benefits can be obtained from human involvement, which essentially represent the capacity to generate knowledge, and innovate to generate output. Another resource that needs to be managed to align goals with outcomes is financial assets. Since our IO model explains that one of the ultimate goals of developing the smart city is sustainability, providing funding for it should also be sustainable. In this regard, there is a new approach for funding smart cities in the literature known as "sustainable finance" which states that funding should not only consider financial aspects of return on investment and profit or loss, but also non-financial aspects, such as responsibility for the future of the city, environmental protection, issues of climate change, and social obligations (Janssen et al., 2012). Sustainable finance concerns long-term term value creation which considers employees, customers, suppliers, the environment, and society as a whole (Hauptmann, 2017).

Governance and leadership throughput refer to the question how the process of transforming a city into a smart city, consisting of different domains, can be governed: i.e., intergovernmental relations, coordination among actors, and leadership capabilities (Hoppe et al., 2016; Bressers et al., 2016) (See Table 2).

"Intergovernmental relations" refers to the interdependency of different organizational layers involved in governing the process and the way these are handled (Bressers et al., 2016). Since there are multiple actors, the interests they bring to the game also vary and the shape these interactions take depends on the political, legal, institutional, and cultural context in which they are embedded (Joss, 2015; Yigitcalar, 2015). "Coordination among actors" elaborates on the question which actors are involved in the process, which interests and perspectives they bring to the table, what responsibilities they have for specific tasks (for instance data ownership), the legal authority granted to them and how key resources are exchanged among them (Bevir, 2012). Various leadership capabilities form the body of decision-making in different ways, in terms of how the process of transformation should be done and goals should be set. Different leadership styles form different ways of processing resources and transforming them to outputs. For instance, in participatory leadership styles leaders often make the final

Table 2. Smart city throughput

Throughput Domains	
Dynamic throughput	Data and infrastructure asset management
	Knowledge and innovation management
	Financial asset management
Governance and leadership	Intergovernmental relations
	Coordination among actors
	Leadership capabilities

Adapted fromGupta et al. (2015) andBressers et al. (2016)

decision in alignment with other stakeholders, so the process of decision-making tends to be slower. Nonetheless in visionary leadership styles, leaders rely on their charisma and personality to make the final decision, in this way decision-making can be fast but the level of acceptance by other stakeholders is based on the level of trust in the leader (Bevir, 2012).

Output

Output refers to the deliverables of smart city policies for which goals are formulated and for which reason the input resources are made available. To characterize these resource-based domains, we again first define them, then indicate how and where they appear when they are applied in the smart city, and finally sketch what their potential is.

Smart Applications. Giffinger et al. (2007) focus on the smart city as a smart transportation system. This is often a key element in smart mobility. However, in the present paper we define it in a broader sense as the innovative mobility capabilities in order to achieve more flexible urban services and benefits. Mobility in fact increases the level of utilization of facilities and services, and accessibility to them. Juniper Research (2017) on the top smart city performance by index indicates that mobility saves considerable time and benefits smart city inhabitants by allowing more time for family and friends, decreasing the risk of depression, and improving earning potential (Juniper Research, 2017). It includes all aspects of smart traffic systems, such as dynamic traffic light phasing and smart parking to reduce time spent in traffic, and open data platforms enabling citizens to choose the fastest option. The results also show that mobility winners have their own smart solutions for urban transportation challenges alongside long-term policies for new paradigms like autonomous vehicles. Some of them, other than focusing on smart solutions, contain strong policies regarding car ownership and reducing the number of vehicles on the road. So, there are different approaches to smart mobility ranging from smart traffic solutions, smart public transportation, and smart private transportation to smart mobile services like shipping packages by drones.

An important feature of the smart city which distinguishes it from other types of techno-driven future cities is having "smart citizens" in place (Cardullo and Kitchin, 2019). In the present paper we define "smart citizens" as interactive and even proactive citizens who are able to produce, share, and benefit from information within the city to accelerate smart and sustainable solutions. One of the main strategies to achieve the goal of smart city development is its strategic use of innovative ICT-based solutions to connect the citizens and technologies of the city on a common platform. Borgia (2014) in an analytical survey states that what most authors have in common is the focus on ICT as an enabler and as an opportunity to empower human capital, i.e., education, awareness, and proficiency of citizens in the use of ICT. This smart empowerment then becomes a primary goal of cities that brand themselves as "smart." Therefore, smart cities, in addition to creating smart solutions based on technology, are required to facilitate the communication between modern technologies and citizens through training and engaging them in the smart city development process through living labs, organizing related events and workshops, and building spaces for idea sharing among citizens.

As Gil-Garcia et al. (2010) argue, the use of ICT infrastructure and the potential of bringing various information streams together is clearly affected by acts of governance and institutional structures. They support the emergence and persistence of stable and trusted social networks (players having confidence in each other and collaborating), and facilitate information-sharing and the building of a platform for smart governance. We make a distinction between "governing a city to become smart" (throughput) which includes making policies and regulatory regimes for smart city development, and "smart government" (output) where the application of ICT is used to transform traditional government and increase efficiency, effectiveness, transparency, and accountability of governance structures and operations through advanced use of information. This also promotes open data to empower citizens by making information more publicly accessible.

Smart energy systems seek to reduce energy consumption through the application of novel technological innovations while promoting energy conservation and material reuse, and thus support the environmental aspect of sustainability. As a result of the other achievements of the smart city (smart mobility), Jeekel (2016) argues that, in response to the question "is smart mobility socially sustainable?" new mobility services are considered to have positive effects on sustainability.

High quality of life is one of the ultimate goals of all human advancement and not exclusive to the smart city. Access to high-quality healthcare services (including e-health or remote healthcare monitoring), electronic health records management, home automation, smart home and smart building services, and easier access—via the Internet—to social services of all kinds are evidence of smart city commitments for a high quality of life. Also, the smart use of new technologies by networks of actors makes cities safer (Meijera and Thaens, 2018).

Externalities. Multiple authors have argued that smart city development is intertwined with two aspects of externality: sustainability and high quality of life (Yigitcanlar, 2015; Mortensen and Jonsbak Rohde, 2012; Gemma, 2014; Zhao, 2011). For instance, Yigitcanlar's (2015) definition of the smart city focuses on sustainably to become an increasingly better place to live, work, and play which essentially covers both aspects. Although the issue of sustainability was initially debated by economists, it was later also picked up by scholars from different academic domains like industrial ecology. The smart city is believed to go hand in hand with sustainability, as it looks committed to contribute to sustainable growth. However, the effects of smart cities can differ; among others they can have social, environmental, and economic effects. According to McKenzie (2004: 18), "social sustainability occurs when the formal and informal processes and structures support the capacity of current and future generations to create healthy, liveable communities." This largely coincides with quality of life. For Littig and Griessler (2005) in the social domain of sustainability, a more environmentally friendly way of life should be supported by smart cities. When economic sustainability is pursued, development is seen as a form of qualitative rather than quantitative growth (Basiago, 1999). Here social, economic, and potentially environmental sustainability coincide with quality of life.

Finally, from an environmental perspective, the smart city should be supportive of reaching ecological sustainability which promises a thriving physical environment as expressed in biodiversity or in minimizing the city's ecological footprint. Mobilized

urban services and the smartness of citizens—the two indicators of safety and livability—stand primarily for quality of life. Nonetheless, depending on the context, policies, and attitudes, there are different interpretations of what quality of life entails, and how it shows overlap with social and economic sustainability.

Illustrative Case Study: Smart Dubai—The "Happiest" City

This section presents the illustration of an iconic example of a well-branded international smart city and shows how different aspects of a smart city development process can be understood as input, throughput, and output, and outcome in the application of the IO-model we have presented (See Table 3).

Different cities branding themselves as "smart" differ remarkably in the things they do. The history of the smart city in Dubai returns to e-government which has evolved into a smart government program and, then smart city development. According to A. Alazzawi (2018), whose title is City Experience Advisor for the Smart Dubai Office, in 2014 Sheikh Mohammad, the Ruler of Dubai, set up an executive office for smart city development that would respond to his innovative idea–"Smart Dubai, the happiest city". This is in line with his vision of "happiness" and "positivity" which states that positivity is a way of thinking, and happiness is a lifestyle (Al Maktoum, 2017). Ali Rashid (2018), the director of the Dubai Supreme Council of Energy, explained that Smart Dubai is part of a transformational mind-set steered by the visionary leadership of the Emirates. Nonetheless the so-called "happiness policy" influences all of the Emirates (Dubai is part of the UAE) as an overarching policy, but the idea and its fundamental attitude were created for Smart Dubai.

Table 3. Applying the IO model to the Smart Dubai case

Elements/Facets of the IO Model		Application in the Smart Dubai Case
Resources (Input)	Modern ICT infrastructure	Dubai Pulse IoT platform
	Human and entrepreneurial infrastructure	Dubai Pulse PPP "Happiness champion" Free zones
	Data	Presence of a shared data platform Dubai Data Establishment
	Financial infrastructures	Governmental funding foreign investment
Throughput	Dynamic capabilities	Dubai Smart City Accelerator Expo 2020 Smart (AI) Lab Sustainable financing
	Governance	Administrative levels: The Ruler of Dubai, Smart Dubai Office
	Leadership	"Visionary" leadership by the Ruler of Dubai
Output	Mobility	Dubai-Abu Dhabi hyperloop, EV
	Smart government and citizens	"Happiness champions" "Happiness meter" DubaiNow App Paper-free government
	Smart energy and health	Shams Dubai E-health program
Outcome	Sustainability	Increasing social, health economic, and environmental performance indicators; but predominantly focused on improving energy efficiency levels.
	High quality of life	"Happiness" in terms of increased satisfaction with public service delivery in a variety of policy areas

In 2015 Dubai and the International Telecommunication Union (ITU) signed an agreement for Dubai's becoming the first city using key performance indicators (KPIs) to assess the smartness and sustainability of its urban services. To provide IoT infrastructure, "Dubai Pulse," which is the digital backbone powering the Smart City, was made responsible for developing an IoT platform.

For data assets, there is a project called "Dubai Data Establishment" (DDE), which oversees the Dubai Data Law; it prescribes that all data the government generates belong to DDE which is a government entity that ensures the presence of a shared data platform (interview with Alazzawi, 2018). The Dubai Pulse official website shows that there are two different categories of Dubai data: (1) open data published by the government or the private sector to be used or exchanged with individuals; and (2) shared data published under certain terms and conditions among the entities. However, there is no information to clarify what type of data is shared or made openly available. To manage data, disseminate information efficiently, and to deliver public services for citizens, "DubaiNow" is supposed to be a single comprehensive application established in 2015 to put all the services in one place. It enables users through a single sign to access various kinds of public services. At the time of writing the present paper, the application was still under development (interview Alazzawi, 2018).

The supporting policy for entrepreneurship is to deploy free zones for attracting businesses where foreign ownership is allowed and zero personal or corporate income taxes are charged. Smart Dubai also has specific policies in place to support start-ups (Smart Dubai Office, 2019). In terms of providing financial resources, the Dubai Smart City program is a government program mainly funded by the Dubai government. Yet, private-sector partners and start-ups have started a wave of sustainable and green fundraising activities supported by the Dubai Declaration on Sustainable Finance (Alassawi, 2018). On the other hand, financing a clean-tech business is not always easy as Daniel Zywietz (2018) founder and CEO of "Enerwhere" states (a solar company with its headquarter located in Dubai). Crowdfunding is one of the solutions his company offers to alleviate financing problems start-ups encounter.

Looking at Smart Dubai's main governing body, the initiator is the Ruler of Dubai. The Dubai Smart City Office is the central implementation body which serves as an independent initiative, and is responsible for the development and implementation of smart programs and solutions while cooperating with other governmental and private-sector entities like the Dubai municipality, Du (a major integrated telecommunications services provider in UAE), DEWA (Dubai Electricity and Water Authority), RTA (Road and Transport Authority), Dubai Pulse, and many other organizations. DEWA was launched in 2014 and started three smart initiatives to support Dubai's smart transformation including Shams Dubai (which pertains to a project regarding photovoltaic solar panel installation on rooftops), smart meters and grids, and the Green Charger for the construction of infrastructure and electric vehicles. Dubai Smart City Accelerator is another initiative within the Dubai Smart City office which also has joined the Dubai Future Accelerators (DFA) program to support innovations and start-ups in IoT and connectivity, smart applications, and sustainable living. Expo 2020 is one of the most extensive of Dubai's programs to foster innovation for a sustainable future by engaging young people and promoting international cooperation. Branding aspects play a crucial role in generating worldwide attention to such events in Dubai.

While the countries with the highest ranking in smart mobility—like Singapore—are mainly focused on reducing the number of vehicles and car ownership, the UAE—considering its cultural context to change consumer behavior—is more focused on smart solutions like electric vehicles (EVs) and increasing the share of electrical vehicles on the roads of Dubai. There is a target of reaching an overall 10 percent share of electrical vehicles for government entities, and a 10 percent share for all vehicles of Dubai by 2030 (interview with Ali Rashid, 2018). In addition, Sypron Solutions, an IoT company, and the first hyperloop company in the Middle East, is to develop a project that constructs a hyperloop infrastructure from Dubai to Abu Dhabi using smart mobility technology (ENGIN, 2018).

In terms of smart energy, DEWA is Smart Dubai's main partner. It launched Shams Dubai as an initiative responsible for making Dubai greener with the installation of solar panels. Green building regulation is a supportive strategy promoted by Dubai's Supreme Council of Energy to create healthy, eco-friendly, and efficient buildings using smart applications.

Dubai Health Authority (DHA) is a public department that pursues the use of smart applications to ensure all hospitals in the Emirate of Dubai eventually adopt the electronic model which will facilitate the provision of better healthcare services to the community (DHA official website, 2018). According to A. Almazami (2018), an official in the Dubai Silicon Oasis, the six month roadmap of Dubai Smart Health (2018–2019) contains four smart applications: (1) patient services: for medication, appointments, and lab results, (2) Dammi: for blood donation, (3) Salem: for medical fitness; and (4) live media and news: for health awareness.

Another dimension in the applications within the realm of Smart Dubai (as a form of Dubai smart government) is the "Government of the Future" which operates 24/7 and 365 days a year. It considers any governmental body successful if it actively engages the citizens and does not passively await them in providing government services (Dubai Smart Office, 2019). There also is a paperless strategy used by the Dubai government. Smart Dubai office has been instructed to oversee this policy and seeks to attain its goals by 2021 and enable this through three pillars: technology, legislation, and creating a culture to support achieving sustainability goals (Dubai Smart Office, 2019).

Sustainability has evolved into a key value of the Dubai Smart City Initiative. There is also a sustainable city district in Dubai, deploying new technologies to achieve social, economic, and environmental outcomes (SEE NEXUS Institute, 2018). Awareness is a key means for realizing the energy efficiency policy and sustainability goals in Dubai. Karim El-Jisr (2018), the executive director of Dubai Sustainable City, said, "What we offer here is not just sustainability, we create a lifestyle. So, if you appreciate this lifestyle, you will begin to appreciate sustainability". At the same interview, Tim Rogmans (2018), an associate professor at Zayed University, further stated that in order to achieve a high quality of life for its "smart citizens," the dominant concept is still related to "happiness." Obviously, Smart Dubai operationalizes quality of life in "happiness" indicators.

When it comes to smart citizens, there is a Smart Dubai "happiness champion" in order to communicate with citizens and stakeholders and to involve them in coordinating, strategizing, and implementing programs and projects in line with the "Happiness" system instead of using living labs. "Happiness champions" are considered part of value creation that seeks to have a shared language and shared understanding and make the co-creation

of policies possible (interview with Alazzawi, 2018). Alazzawi adds: "The main method to evaluate Smart Dubai's performance is to measure and monitor using the 'happiness meter' which demonstrates (increased) 'happiness' of Dubai's citizens in terms of quality of life and satisfaction about the interaction with government bodies" (i.e., appreciating public service delivery).

Discussion and Conclusion

This paper set out with the question how to develop an IO model to support decision-making for developing a smart city based on a conceptual interpretation of its key facets. Our bibliometric analysis showed that the "smart city" has increasingly become a focal point in urban policy and planning practices. Moreover, technological innovation has widened the scope of the smart city. Although the literature is already replete with contributions about various aspects and dimensions of the smart city, thus far no attempt was made to synergize aspects and dimensions of smart cities into a comprehensive conceptual model that can be applied as an IO model to clarify how particular types of inputs and throughputs result in a given output. Having developed such a model enables academics, analysts, and policy-makers to comprehend how design choices with regard to the smart city development, and translate these into particular smart city types or profiles. The content analysis based on the academic literature in the present paper helped us to map the various attributes of the smart city. The subsequent IO modelling exercise based on system theory allowed us to position the key facets of the smart city as found in the literature survey within the framework of an Input-Throughput-Output model and demonstrate the variety of design choices available to policy-makers and analysts when developing a smart city. Finally, we applied the IO model to an illustrative case to show how it can be used to analyze smart city development.

The IO model we developed here explains what the essential input and throughput resources for smart city initiatives are, where and how they appear in making design choices during the smart city development process, and what possible outcomes of the process are. Komninoa and Mora (2018) explored structural axes of the smart city literature generated by a bibliometric analysis as technology-driven vs. human-driven approach, top-down vs. bottom-up planning, and collective intelligence vs. data-driven intelligence dichotomy. The results of applying the IO model we developed to the illustrative case of Smart Dubai shows a specific type of smart city development process, which can arguably be characterized as mainly a top-down process supported by visionary leadership and active branding strategies and actions, a focus on promoting "happiness." This is very specifically defined as customer satisfaction about government services and the involvement of a variety of financial and technological applications to enhance the range of domains affected by Smart Dubai.

A look at the input to Smart Dubai's development process shows that the technology transfer strategy and the deployment of new technology-based smart solutions are important resources. However, the importance of the start-ups and the promotion of innovation was not overlooked. Creating an economic environment to attract innovative companies and start-ups is a strategy Dubai has used to boost the innovative atmosphere and strengthen the development of its human resources. Among the throughputs, the main arm of potency for the Smart Dubai development process is its visionary leadership style

that determines the overarching policy. This overarching policy is the "happiness" policy. Although this sounds like a very positive vision, the challenge is obviously to define and operationalize this elusive concept, making Smart Dubai truly inclusive under the umbrella of this policy, and including all citizens including the migrant labor force. Smart Dubai, through designing a "happiness meter" that aims at operationalizing and measuring the "happiness" policy, has narrowed its actual meaning down in particular ways that may seem odd to people outside the region, but its approach has been embraced in other UAE members and widely acclaimed in the broader Gulf Region. Data management as a dynamic throughput is another aspect of Dubai's smart city focus. Documentation, laws, and guidelines related to data indicate that this issue is of interest in Smart Dubai. What Smart Dubai is looking for as the output of this process, is covering different fields of application ranging from a main focus on energy (which is a major challenge for countries in the region) to smart government and citizens, mobility, and health. Following the energy efficiency and carbon footprint challenges, the environmental sustainability issue is highlighted in many Smart Dubai statements. But to what extent Smart Dubai can live up to that expectation, remains to be seen and should be assessed in the future.

This raises the question how the Smart Dubai experience compares to those in other smart cities, and what the application of the IO model would look like for them? It also raises the question of what crucially different design choices other cities around the world make that seek to become smart cities? Other questions pertain to how do other cities perform in terms of outputs and outcomes? And what can they learn from Dubai and each other to enhance their respective performance? Future study can throw light on these questions, further detail the use of this model, and help policy-makers and analysts make well-reasoned design choices by taking the various components and facets of a smart city into account when developing one.

Notes

1. For more details, please see the methodology section on occurrences per category in the article by De Jong et al. (2015:3).
2. However, some discussions have addressed potential negatives associated with the smart city (Wiig, 2017; Attoh et al., 2019; Barns, 2016).
3. In-depth interviews were held from May 15–May 12, 2018 with 10 smart city stakeholders including: the City Experience advisor, the executive manager, the ideologist of Smart Dubai Office, a professor from Zayed University, the executive director of Sustainable City in Dubai, the executive director and the program manager of TAQATI, the executive director of DEWA, The director of the Dubai Supreme Council of Energy, and the managing director of a magazine called *The Sustainabilist*.

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