Public Administration and Information Technology 37

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Smart Cities and Smart Governance

Towards the 22nd Century Sustainable City

Springer

Public Administration and Information Technology

Volume 37

Series Editor

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More information about this series at http://www.springer.com/series/10796

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ISSN 2512-1812 ISSN 2512-1839 (electronic)
Public Administration and Information Technology
ISBN 978-3-030-61032-6 ISBN 978-3-030-61033-3 (eBook)
https://doi.org/10.1007/978-3-030-61033-3

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

This book is timely, useful, and prescient. By bringing together both the application and research regarding smart cities, the book offers its readers significant insights into the strategic utility of global smart cities initiatives. In addition, the book reminds us of our interconnected policies, technologies, applications, and services at the local, national, regional, and international levels.

In doing so, the book not only serves as a guide for today's smart cities context but also tomorrow's as we struggle on a global scale with the COVID-19 pandemic.

At present, more than half of the world's population lives in a city, with a projected population rate of 60% by 2030 (United Nations, 2018). The rate of densification is accelerating. In 2000, 371 cities had populations of one million inhabitants or more; by 2018, this number had grown to 548, and it is projected that there will be 706 cities with one million or more inhabitants by 2030 (United Nations, 2018).

Simultaneous to this population growth has been an investment in technology infrastructure: broadband; wireless; and increasingly, 5G mobile networking capabilities. Milestones of note in 2019 included (International Telecommunication Union and United Nations Educational, Scientific and Cultural Organization, 2019):

- More than half of the world participated in the online global digital economy;
- There were an estimated 21.7 billion connected devices;
- More than half of households have broadband access globally, mostly concentrated in urban areas; and
- There were an estimated 5.1 billion unique mobile subscribers.

By 2023, it is estimated that 5G wireless technology, with speeds of approximately 10 GB/s, will account for nearly 11% of total mobile connections (up from 0.0% in 2018) (Cisco, 2020).

At the same time as the growth has occurred in urban areas in particular and there have been investments in technology infrastructure, we have witnessed substantial investments in artificial intelligence and big data. Together, artificial intelligence, big data, and data analytics have fostered unparalleled opportunities for governments to better address community needs in critical areas of transportation, environmental impact, health care, citizen services, and more (Mergel, Rethemeyer, & Isett, 2016).

In short, we are at the precipice of a new era of governance due to the intersection of community changes and growth, data, technology, and connectivity—and the integration of devices (broadly defined as in-home devices, mobile devices, vehicles, and other internet-enabled devices) and networks, often referred to as the Internet of Things (IoT).

Core to this new era is the Smart Cities paradigm. Though the notion of Smart Cities has been in existence for some time (Wilhelm & Rhulandt, 2018), emerging technologies are bringing the vision closer to large-scale reality. While until now communities have been able to experiment and implement a range of smart technologies that have offered improvements to governments and the governed, this book documents that the foundation is set for exceptional progress. The realization of this vision is not without its challenges. As the book brings to light, we have various issues to address in key areas of security and privacy, access, policy, governance, and ubiquity, to name just a few. And more recently, due to the COVID-19 pandemic, the intersection of public safety, privacy, innovation, and health care due to tracing apps and other contact tracing mechanisms has shone a light on both the promise and perils of smart technologies and abilities.

This book offers insights into the opportunities, practice, future, and challenges of Smart Cities. The book is destined to be a critical resource for practitioners, policy makers, and researchers who wish to have a foundational understanding of the origins and future directions of Smart Cities.

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Acknowledgment

This book is the result of the dedication of many people who have worked together as the Smart Cities Smart Government Research Practice (SCSGRP) Consortium. The commitment of the Consortium members to the idea of an edited book designed to represent some of the best ideas of the members made this book possible. We are so grateful to them in the many roles they played as authors and reviewers of papers and as enthusiastic supporters of the idea of this book. Particular thanks to Meghan E. Cook, Coordinator of the SCSGRP Consortium for her tireless efforts in managing the consortium. We express specific gratitude to Manuel Pedro Bolivar, Springer PAIT series editor, for his vision and his support. We thank the wonderful team at Springer who were instrumental to our efforts. We also thank Iseul Choi, our editorial assistant who began this project as a doctoral student at the University at Albany, and finished as an Assistant Professor of Public Administration at the University of New Mexico, for all the work she did to make this volume possible. Her professionalism and attention to detail are second to none. We are also grateful to CTG UAlbany, University at Albany, SUNY, from whom we received institutional support for this effort. Finally, we send love and gratitude to our families.

With gratitude,
Elsa Estevez, Theresa A. Pardo, and Hans Jochen Scholl

Introduction

What it means to become a smart city and to engage in smart governance continues to evolve as our understanding of these concepts, in both theory and practice, evolves. Population shifts to cities are a global reality. As the world's population continues to shift from rural to urban, the challenges cities and communities are facing are also evolving. Growth is straining physical and social infrastructures and testing the most innovative of leadership teams to continue to create sustainable value. Cities experiencing reductions in population are struggling as well to find ways to maintain the livability of their cities in the midst of shrinking resources. In parallel with this dynamic is the advent of a new era in technological innovation and new commitments to using innovations, including technological innovations, to making cities and communities "smarter." These phenomena taken together are providing cities with new opportunities to serve those who live and work in those cities. In the smartest cities, technological innovations are situated within a broader context of social, economic, and policy innovations, among others. These cities are experiencing innovations in policy and management, in collaborative governance, and in technological developments that are highly interdependent and context specific.

The notion of a "smart city" as a new and promising avenue in urban government and governance is driving and informing the development of novel and groundbreaking initiatives, such as institutional innovations that enable smart government and governance, the use of 5G technologies for safe autonomous driving, and intelligent steering of infrastructures of all kinds such as power, water, sewage, traffic, emissions, and health indicators. It is raising awareness of the need for new understanding of and models of governance, of new policy priorities, and new regulatory frameworks. It is raising awareness of the need for new understanding of innovation and how to maximize the potential of each investment made in innovation; it is raising awareness of the need for new approaches to technology adoption and use in cities and new approaches to management of those technologies in ways that ensure sustainable value creation.

This edited book is a product of the Smart City Smart Government Research Practice (SCSGRP) Consortium, an international, multidisciplinary network of smart city scholars. Its 16 peer-reviewed chapters from Consortium members provide a roadmap for some of the latest concepts and practices in smart city and smart government. Taken together, the chapters provide a foundation for any effort seeking to understand, envision, and prepare for a next-generation city. They advance a global understanding of the nature of and need for novel concepts, theories, and frameworks, as well as innovative policies, administrative practices, and enabling technologies.

This chapter is organized in eight sections including this introduction section. Section "Creating an International Research Practice Network: A Short History of the SCSGRP Consortium" provides a short history of the SCSGRP Consortium. This history highlights the strength of the digital government community as it continues to grow and adapt. Section "A Unique Addition to the Body of Knowledge on Smart Cities" highlights the novelty of the collection and introduces the organizing framework for the chapters. Sections "Governance", "Policy", "Innovation in Smart Cities", and "Technology and Management" provide summary statements about each of the chapters. Section "Who Should Read This Book?", the final section of this introduction, makes clear the value of the book to the range of potential readers.

Creating an International Research Practice Network: A Short History of the SCSGRP Consortium

The SCSGRP Consortium is the product of a number of key initiatives that began as early as 2005 when the U.S. National Science Foundation (NSF) funded the *Building an International Digital Government Research Community* (dgi) project at the Center for Technology in Government at the University at Albany (CTG UAlbany), State University of New York.[1] The goal of that 4-year $1.5 million dollar project was to create a framework for a sustainable global community of practice among digital government researchers and research sponsors. The project included an international reconnaissance study describing the current status of digital government research, an annual research institute, and a framework for several international working groups.

The North American Digital Government Working Group (NADGWG), one of the four working groups supported by the NSF grant and the home institutions of the members, was formed in 2007 by a group of researchers and practitioners from a variety of disciplines and institutions in Canada, the United States, and Mexico.[2] NADGWG was organized to advance digital government research across geographic and political boundaries in North America. With this focus and recognition of the rapid evolution towards a more global perspective on the social, political, and economic issues facing the three nations, the working group focused on understanding

[1] https://www.ctg.albany.edu/projects/dgi/

[2] https://www.ctg.albany.edu/projects/nadgwg/

new requirements for how individual nations respond to public problems and about how nations work together in response to transnational problems. Of particular interest was the new forms of government enabled by technologies and made possible through new models of cooperation and collaboration. NADGWG ultimately transitioned into two working groups, the first, supported by a second NSF grant,[3] focused on building transnational trustworthy organic food inspection and certification systems and the second focused on the emerging phenomenon of the "smart city."

To support their efforts to engage doctoral students in the research, the NADGWG Smart Cities Working Group applied for and received a grant from the Social Science and Humanities Research Council (SSHRC) of Canada. This grant complemented the goals of NADGWG and the overarching *Building a Digital Government Research Community* grant, to advance international digital government research and build the next generation of international DG scholars and practitioners by supporting doctoral students at each of the home institutions. Because of that support, the students at each institution were able to work as full members of the Smart Cities Working Group. The working group conducted a comparative case study of seven cities in the three countries of NA. This highly successful effort resulted in the development of a set of seminal articles on smart cities, including Chourabi et al. (2012), which presents one of the first frameworks for understanding smart cities.[4] Over time, it became clear that the NADGWG Smart Cities Working Group provided a model for engagement among the ever-expanding community of researchers focused on understanding the digital transformation occurring in many of the world's cities.

With this vision in mind, the Smart Cities Smart Government Research Practice Consortium (SCSGRP Consortium) was officially formed in 2012 to advance the state of both research and practice of smart cities.[5] Based at the Center for Technology in Government at the University at Albany, the SCSGRP Consortium is grounded in a shared commitment to both advancing scholarship and practice of smart cities and smart government and working collaboratively to build new and innovative research practice partnerships that span the globe. This international multidisciplinary consortium brings together members to share knowledge and research results, to form new interdisciplinary and multi-national teams to generate new research results, to work through public-private partnerships to translate research findings into practice guidance, and to work collaboratively towards better understanding of the various facets of "smartness" in urban government and governance.

Today the SCSGRP Consortium is a globally unique scholarly community comprised of more than 40 of the world's leading smart city scholars from 35 universities in 25 countries. Through careful management, purposeful networking, and connected research, Consortium members come together regularly through virtual management meetings and lightning talks and co-located events to share ideas, new

[3] https://www.ctg.albany.edu/projects/ichoose/

[4] https://www.ctg.albany.edu/publications/hicss_2012_smartcities/

[5] https://www.ctg.albany.edu/projects/smartcitiesconsortium/

knowledge, and research and practice innovations in the interest of increasing opportunities for all those who live and work in the world's cities. SCSGRP Consortium members have worked systematically through quarterly management meetings to build and strengthen a foundation for interdisciplinary and multinational research. The number of smart cities publications produced by members both independently and through research and writing partnerships formed through the Consortium networking events continues to grow as well as the recognition of the significance of these publications to smart cities research and practice.

Reflecting the Consortium's commitment to knowledge sharing and networking, members have co-organized more than twenty full and half-day workshops and panels. Workshops and panels have been organized around premier digital government and public administration conferences including the international Digital Government Research conference (dg.o), the Digital Government Track at the Hawaiian International Conference on System Sciences (HICSS), IFIP EGOV-CeDEM-ePart, the International Conference on Electronic Governance Theory and Practice (ICEGOV), and the American Society for Public Administration (ASPA). Consortium workshops have provided a forum for members and others interested in or engaged in smart cities-related research and practice to come together around paper presentations, lightning talks, research agenda setting discussions, and partnership building. Numerous additional research and practice conferences and symposia have been organized and conducted by Consortium members in partnership with their practice colleagues in cities around the world.

A Unique Addition to the Body of Knowledge on Smart Cities

This edited book is a unique addition to the body of knowledge on smart cities and a much-needed source reflecting on the current and future developments of "smartness" in urban government and governance. This book is provided to inform academics, researchers, and practitioners as they work, ideally together, to understand the dynamics of cities today and into the twenty-second century, and to generate new knowledge that will translate into sustainable value creation for the world's cities.

The primary contribution of the book is exposure to a collection of chapters by an established and global network of scholars actively engaged in smart city smart government research and practice. Collectively, the chapters contribute to this research and practice communities through new theoretical frameworks, policy models, practical models, and approaches. They present a global view of emerging issues, questions, and research problems, as well as case studies from different parts of the world.

True to the principles of the Springer Public Administration Information Technology Series, the chapters in this book bridge both theory and practices in their examinations of both the successes of Information and Communication Technology (ICT) adoption and some of the most important challenges to implementation in cities. The chapters address new and emerging technologies from both a developed and developing country perspective and from across all sectors, with the goal of providing important lessons for public managers and policy analysts.

The 16 chapters present contributions from 43 authors spanning a range of theoretical approaches, methods, policy domains, and geographic locations, among others. The chapters include essays, literature reviews, conceptual and theoretical discussions, and empirical work. The chapters are presented in four general topic areas of (1) governance, (2) policy, (3) innovation and smart cities, (4) technology and management.

Governance

Three chapters contributed by SCSGRP Consortium Members make up the Governance section of this book. The first chapter of the section presents the results of a bibliometric study and mapping exercise showing that academic research on smart governance "appears to advance in a fairly systematic and almost all-encompassing fashion." The second chapter theoretically and empirically contrasts open governance with existing work on governance. The third calls attention to a set of organizational characteristics that are relevant for smart city governance and highlights three building blocks for smart city governance.

In the first chapter of the book, "Smart Governance: Analyzing 5 Years of Academic Output on the Subject Matter," Hans Jochen Scholl conducts a bibliometric study and a topical mapping exercise which sheds light on the emphases and topical directions of smart governance-related academic research. Based on the 2014 Smart Governance Framework (Scholl & Scholl), this empirical study found that the six-by-eight matrix, which lists six elements of smart governance against its eight focus areas as presented in the 2014 framework, helped to identify gaps in the academic attention of the elements of "skills and human capital," "electric mobility," and "participation and collaboration." These findings notwithstanding, almost 94% of elements and focus areas were covered by academic research, that is, academic research appears to advance in a fairly systematic and almost all-encompassing fashion. Overall, the empirical study illustrates the analytical usefulness of the 2014 Smart Governance framework.

In their chapter, "Path Dependency of Smart Cities: How Technological and Social Legacies Condition Smart City Development", Albert Meijer and Marcel Thaens discuss how results of previous projects influence the future construction of a smart city. By analyzing the experiences of two projects conducted in the City of Rotterdam, in the Netherlands, they illustrate how an information infrastructure and a network of innovators established in past projects constitute main enablers to future developments. Through an in-depth analysis of the case study, they develop a theoretical perspective on the path dependency of continuous efforts towards the development of a smart city. They highlight the need for understanding past efforts to assess how a city may evolve.

In the final chapter in this section, "Government Characteristics to Achieve Smart Urban Governance: From Internal to External Transformation," Erico Przeybilovicz and Maria Alexandra Cunha present an overview of organizational characteristics of local government that are relevant for smart city governance, introducing and discussing in depth the concept of smart urban governance. The authors distinguish three building blocks for achieving smart urban governance, which comprise (a) participation, collaboration, and co-creation in providing services and information, (b) government support and contribution in terms of funding, technology provision, and provision of civil servant expertise, and (c) management of the legal context and the strategic direction and alignment on part of local governments. According to the authors smart urban governance might lead to both internal (administrative) and external (interactive) transformation in the urban model of governance.

Policy

The four chapters in the Policy Section of this book together provide readers with new understanding of policy instruments being used to guide the development of sustainable cities. The second "AI Regulation for Smart Cities: Challenges and Principles," presents a set of principles for use in addressing regulatory issues surrounding new and emerging technologies such as artificial intelligence (AI). Chapter three "Creating Public Value in Cities: A Call for Focus on Context and Capability," of this section presents an essay on the need for attention to context in establishing smart city programs and priorities. The fourth and final chapter "The Green Dimension in 11 Smart City Plans: Is There an Environmental Ethic Embedded in Long Term Strategic Commitments?" of this section presents the results of a set of case studies focused on building a new understanding of the impact and value of smart cities plans on the specific policy priority of environmental sustainability in cities.

In their chapter "Review of International Standards and Policy Guidelines for Smart Sustainable Cities," Elsa Estevez, Karina Cenci, Pablo Fillottrani, and Tomasz Janowski present the results of an exploratory research and comparative policy analysis focused on international standards and policy guidelines with stated goals to support the development and management of smart sustainable cities. In their chapter the authors identify and analyze international standards and regional policy recommendations for the development of smart sustainable cities. In particular, standards formulated by the International Organization for Standardization (ISO) and the International Telecommunication Union (ITU) and guidelines for smart cities in Europe, Arab cities, and the BRICS countries (i.e., Brazil, Russia, India, China, and South Africa) are presented and compared.

In "AI Regulation for Smart Cities: Challenges and Principles," Ya Zhou and Atreyi Kankanhalli discuss smart city dimensions, AI system components, smart city AI applications and their regulatory challenges, and the principles for regulation of smart city AI. The authors present an argument that while many new technologies, such as AI, are being implemented to support various smart city functions, the current approach to resolving legal and ethical challenges to their development and use is fragmented. To address this fragmentation, Zhou and Kankanhalli identify common principles that could help regulate AI systems for smart cities, in particular, they note, to help governments and businesses to form a cohesive view towards the design and implementation of AI for smart cities.

In “Creating Public Value in Cities: A Call for Focus on Context and Capability” Theresa A. Pardo, J. Ramon Gil-Garcia, Mila Gascó-Hernández, Meghan E. Cook, and Iseul Choi present an essay arguing that making a city smarter rests on the capability of that city to create new public value for citizens. In this view, such capability is a function of the extent to which a city is cognizant of its own policy, management, technology, and data context and how it uses such knowledge to create context-specific innovations that are value generating and sustainable.

In the final chapter of the Policy section of this book, “The Green Dimension in 11 Smart City Plans: Is There an Environmental Ethic Embedded in Long-Term Strategic Commitments?,” Olga Gil seeks to test the extent to which an environmental ethic is embedded in long-term strategic commitments in smart city plans, and specifically how the environment dimension of smart cities is addressed in those plans. Through the use of eight case studies over three continents, Gil examines the nature of the commitment to the “green dimension” of smart city plans.

Innovations in Smart Cities

The four chapters in the Innovation in Smart Cities section present a set of new methodologies, models, and frameworks as well as new understanding about what makes a city smart. The first chapter in this section provides a novel methodology for participatory planning of smart city initiatives, the second introduces an urban data business model framework, and the third is about advanced work on ICT-enabled social innovation. The final chapter in the Innovations in Smart Cities section focuses specifically on public value and quality of life in cities.

In “A Methodology for Participatory Planning of Smart City Interventions,” Charalampos Alexopoulos, Loukis Euripidis, and Yannis Charalabidis draw attention to the lack of sound methodologies to support the planning of required participatory planning activities in many smart cities initiatives. Using a detailed taxonomy of smart city actions they present and apply their methodology for the required participatory planning aspects of smart city initiatives. The authors report on the use of their methodology and the insights related to perceptions, priorities, and the generation orientation of cities and municipalities. In particular, they report on the convergences and divergences of these two important stakeholders that become apparent in the process and present a set of strategies for leveraging the convergences and understanding the divergences.

In their chapter “An Urban Data Business Model Framework for Identifying Value Capture in the Smart City: The Case of Organicity,” Shane McLoughlin, Giovanni Maccani, Abhinay Puvvala, and Brian Donnellan argue that urban data business models are not well understood. Using an embedded case study method, they study 40 urban data projects to derive an ontological framework for understanding and classifying such models. They offer the model as a resource for both researchers and practitioners in their efforts to understand the barriers and challenges in urban data business model development.

In the third chapter of the Innovations and Smart Cities section, "Towards Smart Governance: Insights from Assessing ICT-Enabled Social Innovation in Europe," Gianluca Misuraca, Fiorenza Lipparini, and Giulio Pasi build on prior results of research on "ICT-Enabled Social Innovation to support the implementation of the Social Investment Package" (IESI), to contribute to the debate on the development of new smart governance models in the social innovation domain. In particular, they show in their empirical piece that systemic initiatives are mainly happening at the local level and public authorities have a key role acting as catalyzers and enablers of social innovation and digital governance.

In the final chapter of the Innovation in Smart Cities section, "Analyzing the Influence of the Smart Dimensions on the Citizens' Quality of Life in the European Smart Cities' Context," Manuel Pedro Rodríguez Bolívar focuses on the recent conceptualization of public value in smart cities as a strategic approach to public management. In particular, he focuses on the goal that many cities are pursuing, namely to improve the quality of life for citizens. In this empirical piece, Rodriguez Bolivar presents interesting new insights about the links between smart cities, smart dimensions, and quality of life for citizens.

Technology and Management

Five chapters contributed by SCSGRP Consortium Members make up the Technology and Management Section of this book. The first chapter of the section draws attention to the opportunities and challenges of two cutting-edge technologies and the second elaborates on current thinking about information systems in government. The remaining three chapters provide in-depth case studies of specific pilot projects in three cities engaged in explorations into the use of wireless sensor networks, an IoT architecture comprising a set of open APIs, and a platform for integrating and managing geo-referenced Internet of Things (IoT) data, respectively.

In their chapter, "Smart Cities in the Era of Artificial Intelligence and Internet of Things: Promises and Challenges," Amal Ben Rjab and Sehl Mellouli present a literature review aimed at identifying cutting-edge technologies used to transform a city into a smart city. Based on the results, they discuss the roles that two such technologies, Internet of Things (IoT) and Artificial Intelligence (AI), play in the development of smart cities. In addition, the authors identify opportunities and challenges related to their usage and possible strategies aiming at their responsible adoption.

In "Living Apart Together? Discussing the Different Digital Worlds in City Government," Evert-Jan Mulder elaborates on the evolution of information systems in government and, in particular, at the city government level. Based on some existing models in the literature, Mulder proposes an integrated model of information systems used by city governments and discusses the challenges for developing an integrated approach, mainly related to the business value, evolution, funding, new mindsets and skills of the workforce, standardization, and some ethical issues.

In "Wireless Sensor Network in Smart City Pilots: The Case of Salerno in Italy (from 2015 to 2019)," Giuseppe Di Leo, Matteo Ferro, Consolatina Liguori, Antonio Pietrosanto, Antonio Pietrosanto, and Vincenzo Paciello present the experience of a pilot project deploying Advanced Metering Infrastructures (AMIs) in the city of Salerno, Italy. The authors assess the experience of installing 2500 devices for gas and water metering, car parking management, and elder tele-assistance services. They consider the design of some prototypes of Particulate Matter (PM) sensors and their integration into a city infrastructure and discuss the relevance, major benefits, and barriers of AMIs for smart cities.

In the fourth chapter of this section, "Building a Smart City Platform: A FIWARE Example," Peter Salhofer, Julia Buchsbaum, and Michael Janusch present an Internet of Things (IoT)-based architecture based on a platform called FIWARE comprising a set of open application programming interfaces (APIs). The authors propose a solution for a city to capture data from environmental sensors and to integrate such data for use in visualizations through a smart city dashboard.

In the final chapter of the Technology and Management section of this book, "Toward an Open IoT Implementation for Urban Environments: The Architecture of the DBL SmartCity Platform," Siniša Kolaric and Dennis Shelden describe a platform for integrating and managing geo-referenced Internet of Things (IoT) data. The authors explain some functional features of the platform, such as those related to storing, processing, and integrating Building Information Modeling (BIM), spatial, sensor, and 3D data collected in urban spaces. In addition, they discuss the non-functional attributes of the proposed platform, like openness, scalability, interactivity, and modularity.

Who Should Read This Book?

The primary audience for this book is academics and researchers from public administration, political science, information science, and information systems from around the world as well as policy makers and government officials who are interested in expanding their understanding of the smart cities context. This book provides such readers with a set of papers that span the critical areas of governance, policy, innovation in smart cities, and technology and management. These topical areas provide the reader with both a depth of knowledge and a breadth of context and treatment of smart cities and smart governance. Academics engaged in research and teaching in the aforementioned fields, as well as instructors in higher education, and strategists and planners in the public and private sectors will find the range of literature reviews, essays, case studies, and empirical work valuable to their efforts.

Because of the range of topics and treatments, the book is suitable for use in a university classroom or seminar. In particular, the book is suitable for public administration courses that cover institutional and administrative innovation, in particular, in local government; informatics courses that teach the development and implementation of applications and the wide range of data issues; and urban studies courses that teach about context and factors influencing urban environments including sustainable cities.

Contents

The original version of this book was revised. The correction is available at https://doi.org/10.1007/978-3-030-61033-3_17

About the Editors

Elsa Estevez is UNESCO Chair on Knowledge Societies and Digital Governance at Universidad Nacional del Sur, an Independent Researcher at the National Council of Scientific and Technical Research (CONICET), and Full Professor at the National University of La Plata, all in Argentina. She is also a consultant for Inter-American Development Bank (IADB) on the matters of digital government, particularly in Latin America. Previously, she was a Senior Academic Program Officer and Academic Program Officer at the United Nations University (UNU) in Macao and Portugal; Visiting Professor at the National University of Rio Negro, Argentina; Gdansk University of Technology, Poland; University of Minho, Portugal; and head of Information Technology (IT) departments in large financial and pharmaceutical organizations in Argentina. She consulted for governments, taught to public managers and policy makers, and organized events about digital government in over 30 countries. Her research interests cover the structuring of the information technology function in government, digital transformation of government-citizen relationships, and the impact of such transformation on nations' and cities' capacity to pursue sustainable development.

Theresa A. Pardo is Director of the Center for Technology in Government (CTG UAlbany), University at Albany, State University of New York (SUNY). She also serves as Special Assistant to the President at the University at Albany, as a Full Research Professor of Public Administration and Policy at UAlbany, and an Affiliate Faculty in Information Science. Dr. Pardo serves as OpenNY Adviser to New York State's Governor Andrew Cuomo, Chair of the U.S. EPA's National Advisory Committee, as a member of the Business and Operations Advisory Committee of the U.S. National Science Foundation, on the User Working Group of the NASA Socioeconomic Data and Applications Center, and as a Board Member of the Center for Open Data Enterprise. Dr. Pardo is founder of the Smart Cities Smart Government Research Practice Consortium, is ranked among the top five digital government scholars in terms of citations to her published work, and in 2018 and 2019 was named one of the Top 100 Influencers in Digital Government globally. In 2019 she was elected a Fellow of the National Academy of Public Administration. Dr. Pardo holds a Ph.D. in Information Science from the University at Albany, SUNY.

Hans Jochen Scholl serves as a Full Professor in the Information School at the University of Washington, Seattle, WA. He earned a Ph.D. in Information Science from the University at Albany, State University of New York, and also holds a master's degree in Business Administration from the GSBA Zurich, Switzerland. His research interests focus on the information perspective for understanding human-originated complex systems. He employs quantitative and qualitative approaches ranging from System Dynamics to Situational Action Analysis and Action Research among other methods. His areas of study include information management, in general, and digital government, disaster studies (Disaster Information Management), information artifact evaluation, and pro sports information management, in particular. Jochen is a past president of the Digital Government Society, of which he was a founding member. He also serves as Past Chair of the IFIP WG 8.5 (IS and Public Administration) and as Board Member of the International Association for Information Systems for Crisis Response and Management (ISCRAM organization). With the help of iSchool graduate assistants, he maintains and publishes the Digital Government Reference Library (DGRL) and the Disaster Information Reference Library (DIRL). Furthermore, Jochen served as founding chair for over a decade and later as co-chair of the renowned Digital Government Track at HICSS (until 2020). He serves as Associate Editor and Editorial Board Member on a number of leading journals.

About the Authors

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Part I
Governance

Smart Governance: Analyzing 5 Years of Academic Output on the Subject Matter

Hans Jochen Scholl

Abstract In 2014, Scholl and Scholl presented their now frequently cited "roadmap for research and practice" broken down into a matrix of eight "focus areas" and seven "elements of smart governance." This "Roadmap" intended to help researchers navigate their paths through the relatively complex subject matter of smart governance in the public sector given the multiple interdependencies and topical interconnections within the proposed matrix. Since that time, scholastic research on the subject matter has indeed mushroomed and covered almost the entire spectrum that Scholl and Scholl's Roadmap had laid out. With 171 identified research studies this chapter documents the actual overall coverage and pinpoints the few open spots. It also briefly reviews and discusses examples of research in the eight focus areas. Furthermore, the chapter determines major themes that permeate the research on smart governance in the public sector. Based on the illustrative review, it is concluded that the 2014 Roadmap has indeed been useful to identify potential gaps in research but also further guide empirical and theoretical research on the subject matter.

Keywords Smart governance · Public sector · Digital government · Bibliometric analysis · Smart governance research roadmap · Literature review

Introduction

Academic research uses "theoretical lenses," "theoretical frameworks," "conceptual frameworks," "roadmaps," and a number of other similar notions and descriptive terms like "conceptualizing" and "theorizing" to outline either the starting point, or the main focus, and/or the result of an academic report. Most such "framework," "concept," or "roadmap" articles in Digital Government research—see the Digital

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_1

Government Reference Library (DGRL), version 15.0 (Scholl, 2019) appear to pursue the latter two approaches, that is, they develop and present such conceptual/theoretical frameworks and roadmaps rather than using them as guides for presenting empirical research. To give a perspective, in DGRL version 15.0, a total of 458 entries (or, 3.8%) had "framework" in the title, an average of 1480 (or, 12.6%) of entries had either "framework," or "concept," or "theory/theoretical" in the abstract, and the intersections of either "conceptual framework" or "theoretical framework" was found in the abstracts of a total of 808 entries (or, 6.9%). In other words, based on these numbers an informed, yet conservative, guess would suggest that about 7% of the known Digital Government literature develops and presents frameworks and roadmaps of some kind. While nothing is wrong with such conceptual and theoretical undertaking, it also appears that the ex-cathedra framework and roadmap production in Digital Government research is frequently the start and end result, that is, the framework/roadmap appears to be never used for any empirical research. Based on the DGRL one could now proceed and identify who in the scholar community developed which framework/roadmap, who developed the most unused frameworks, and so on. However, that would rather be the subject of a different study or the evaluation of a tenure and promotion case, so that avenue is not pursued hereafter.

Rather with this study, the explicit claim and promise of the 2014 "Roadmap" of smart governance research (Scholl & Scholl, 2014), which was to guide, structure, and analyze the body of knowledge on the subject matter, is honored, and the roadmap has been used here as prescribed in the review of the respective literature and the related bibliometric investigation. For the 5 years since the roadmap article had appeared, 171 academic and peer-reviewed articles were identified, which served as the basis for this review and analysis. This dataset of publications is not exhaustive, which means that some "cells" in the matrix could have been way more populated. However, for the purpose of this study, which seeks to illustrate the topical directions and emphases in the respective focus areas as well as to identify some gaps, where little or no research could be identified, the dataset entirely suffices. It sufficiently supports also the second, bibliometric portion of this study, in which author-defined keywords (after consolidation) and their thematic relationships were mapped and analyzed for identifying major "themes," which permeate the academic research on smart governance in the public sector.

The chapter is organized as follows: First, the "review" literature on smart governance in the public sector, that is, other "roadmaps" and "frameworks" on the subject matter, is presented and discussed. Second, the research questions along with the methodologies employed for the summary reviews and the keyword mapping are detailed. Next, the select literature in the eight "focus areas" is portrayed. Then, the findings of the keyword mapping are presented followed by a discussion of the findings in both portions of the study. Finally, the implications of this study for the roadmap and future research are deliberated accompanied by concluding remarks.

Review of the "Review, Roadmap, Framework, and Related Literature"

This section portrays the 2014 "Roadmap" article (Scholl & Scholl, 2014) first, which tried to develop an understanding of (1) what the elements of smart governance in a smart and open government environment were along with the interaction of those elements, and (2) what kind of research and practice agendas would be supportive of the development and evolution of smart governance in the public sector. Guided by Wilke's conception of smart governance (Willke, 2007), which emphasizes resiliency of government operations by means of adaptive capabilities, and Johnston and Hansen's findings regarding elements of smart governance (Johnston & Hansen, 2011), Scholl and Scholl empirically identified eight focus areas of public administrations in the first half of the twenty-first century (Scholl & Scholl, 2014). Governments they argued would have to prominently address and work on these focus areas in a novel and smart fashion with a smart governance model as a prerequisite. In order to understand the various aspects and implications of such an approach, they combined the seven elements from the Johnston and Hansen study (norms, policies, practices, information, technologies, skills, and other resources) with the eight focus areas (budgeting/controlling, government modernization, security and safety, high-speed connectivity, electric mobility, participation and collaboration, open data/big data, and open government) developed from their own case study and proposed to use the resulting matrix/roadmap as a guide that informs research and practice in the respective problem space (see Table 1).

Scholl and Scholl discussed the way the "Roadmap" was supposed to be used element by element and also requested to include research on outcomes, which could be categorized as "problematic" (Scholl & Scholl, 2014). The authors distinguished between "type A" problematic outcomes (desirable, but unsuccessful) and "type B" problematic outcomes (undesirable, but successful) and urged colleagues and practitioners to also acknowledge and study problematic such outcomes for deeper understanding and better mastery of the subject matter. In the authors' view, the evolution of smart governance was the centerpiece of the unfolding attainment of smartness in infrastructures, public-sphere interactions, public administration, and societal security and safety, all of which would constitute an improved state of smart and open government compared to traditional democratic government. Other studies since, many of which were reviews, while others were empirically based, have described elements and aspects of smart governance, which were already contained in the matrix/roadmap discussed above.

A 2015 empirical study (Lin, Zhang, & Geertman, 2015) argued that smart governance should be considered closely connected to the topic of social sustainability. The authors saw the massive and rapid influx of villagers in cities (ViCs) as a major challenge for urban sustainability and planning, which required participatory and inclusive smart governance, which was supported by modern information technologies such as geographical information systems and planning support systems. A

Table 1 The smart governance research and practice "Roadmap" (Scholl & Scholl, 2014)

	Budgeting/ Controlling/ Evaluating	Electronic Government/ Administrative Modernization/Process Streamlining	Security and Safety	Infrastructure Overhaul and Ubiquitous High-speed Connectivity	Electric Mobility	Participation and Collaboration	Open Data/ Big Data Provision and Use	Open Government, Transparency, and Accountability
Norms	Per focus area the elements of smart governance need to be addressed in detail							
Policies								
Practices								
Information								
ICTs and Other Technologies								
Skills and Human Capital								
Other Resources								

meta-study uses the consultancy lingo-breathing term of "smartization" when superficially comparing smart city initiatives in London, Stockholm, and Montreal (Ben Letaifa, 2015). While the study adds little, if any, novelty to the topic of inquiry, it claims that "smart cities differ from intelligent and creative cities by offering a balanced centricity among technology, institutions, and people" (p. 1415). It also offers a "SMART model," which, however, is starved from a lack of corroboration and academic explanation. In a 2015 editorial introduction of a book, *Transforming City Governments to Successful Smart Cities*, the author assesses that information and communication technologies (ICTs), while necessary in the context of smartness of governance and government, are nevertheless not sufficient prerequisites for a smart city (Rodríguez Bolívar, 2015). Other dimensions as laid out in the highly cited Smart City Framework of 2012 (Chourabi et al., 2012), the author maintains, also play major roles. In a 2016 review of the smart city governance literature, the authors maintain that smart governance was to be studied along the lines of "an emergent socio-techno practice, …a transformation and conservation of urban governance institutions, … <a> contribution of smart city governance to both economic growth and other public values, … <and regarding the—insertions by author> politics of smart city governance" (Meijer & Rodríguez Bolívar, 2015, p. 404). Another literature review of the same year finds that smart governance pertains to and should be studied on multiple levels inside government and outside government, that is, communities (Meijer, Gil-Garcia, & Rodríguez Bolívar, 2016). The authors also hold that smart city governance is a sociotechnical phenomenon warranting the study of both the social actors and their settings as well as the ICTs involved, which might also influence the creation of novel public value. Yet another study of the same year (Rodríguez Bolívar & Meijer, 2015) proposes a "smart governance model" of three main building blocks (strategies for implementation, arrangements, and outcomes), which the authors propose to apply to various types of research (configurations, impacts, and differences in configurations of smart governance). Five empirical case studies described and compared evolving governance structures in various smart city projects (Alawadhi & Scholl, 2016; Barns, 2018; Lopes, 2017; Scholl & AlAwadhi, 2016a, 2016b), the first three of which with reference to the Smart City Framework (Alawadhi et al., 2012; Chourabi et al., 2012). The most recent review on the subject matter of smart governance attempts to connect elements of traditional technology stage models (that have been found speculative about the evolution) of e-government with the concepts and practices of smart government, which subsequently, the authors claim, lead to and require the evolution of smart governance, in general, and in the context of smart cities, in particular (Pereira, Parycek, Falco, & Kleinhans, 2018). While the review enumerates a large number of contributions to the subject, it appears to struggle with regard to synthesizing previous theoretical and empirical contributions. Last, a 2018 study investigated governance models in smart cities relative to the creation of public value (Rodríguez Bolívar, 2018) and suggests that more collaborative and participatory governance models lead to higher public value creation as part of smart city evolution.

In summary, since its appearance the research and practice roadmap on smart governance in the public sector, or, for short, the "Roadmap" (Scholl & Scholl, 2014), no paucity of new reviews and empirical studies on the subject matter of smart governance can be observed. In most study domains, sometimes strongly enforced by gatekeepers such as journal editors and conference organizers, research thoroughly and carefully builds upon each other. However, in Digital Government Research, in general, and in the case of smart governance in the public sector, in particular, it appears that these above portrayed, quite many studies have rarely, if ever, built on each other, which makes the deeper and shared understanding of smart governance in the public sector rather more arduous. Despite its formal quotation in later articles (obviously for covering the bases) the ignorance of previous research manifests itself in even more effective and blatant ways. When previous research is practically silenced by formal (and, what can be called, insincere) quotations, it is rendered insignificant and subsequently obliterated. This non-collaborative practice does not only prevent intellectual scrutiny and discussion, but it rather also effectively hampers the domain of Digital Government Research and its intellectual contribution from advancing.

Research Questions

As stated above, this study attempts to understand how research on smart governance in the public sector has evolved over time before the backdrop of the Roadmap. It also tries to identify and map topical relationships within the subject matter, which leads to the two following research questions.

RQ#1: *In light of the Roadmap, how has academic research evolved, and which of the Roadmap's focus areas and elements has research covered?*

RQ#2: *What relationships of themes and topics are found inside the academic research on Smart Governance in the Public Sector, and what is their relative weight?*

Methodology

Sample and Searches. For identifying academic research for each cell of the Roadmap, primarily Google Scholar was used. While other literature studies based on keyword searches have traditionally confined themselves to using only commercial academic databases such as ABI/Inform (Proquest), ISI Web of Science, and Scopus EBSCO, for the purposes of this study the Google Scholar approach was seen as superior for reasons of currency and completeness, conference papers and book sections were also to be considered, many of which were missing from the traditional databases. For each of the 56 cells of the Roadmap, an iterated search of the format "focus area" AND "element" was conducted, for example, "Safety and Security" AND "Policies." For the search results a custom range was established, which excluded hits before the year 2014, when the Roadmap was published. The results were inspected one by one, and hits that had no relationship to the public sphere were immediately excluded. The searches were iterated with the aim of resulting in at least three hits per cell. Targeted searches using the same search terms and ranges were conducted within the DGRL versions 14.0 and 14.5 in cases of insufficient numbers of hits from the Google Scholar searches.

Data Collection. The initially found articles were downloaded either directly from the Google Scholar site, if available, or retrieved via the University of Washington's electronic journal system; in some cases, interlibrary loan requests produced the articles. All articles were individually inspected and selected based on their topical relatedness to governance in the public sphere. For all selected articles the respective bibliographic references were retrieved.

Data Preparation and Cleaning. The references were inspected one by one for completeness and correctness. All reference records were inspected for containing keywords and abstracts. In cases of missing abstracts or keywords, these were transferred, that is, copy/pasted from the electronic version of the article. In some rare cases keywords needed to be created from the abstracts or the introductions. Keywords were consolidated to avoid underrepresentation, for example, "Internet of Things" and "IoT" to just "IoT," and "policies" and "policy" to just "policy," etc.

Data Analysis. For the cell-by-cell analysis (RQ#1), the respective articles were inspected and summarized. The summaries were compared as detailed in the findings section. In terms of the topical mapping (RQ#2), the RIS file containing the full article references was used as an input to the VOSviewer tool (Van Eck & Waltman, 2009, 2011). By means of the frequency table of keywords, term maps were created, which show the relationship of terms and the relative weight of their links.

Findings

Ad *RQ#1* ("*In light of the Roadmap, how has academic research evolved, and which of the Roadmaps' focus areas and elements has research covered?"*)

In the following for each of the eight focus areas as defined in the Roadmap, one, if any, article is briefly presented, which serves as a placeholder for other articles found for that particular cell of elements of smart governance. In the appendix, the full list of references for each focus area is provided and for each element in it. Furthermore, for each focus area, a small table provides a quick overview of the number of publications identified for each element in the respective focus area.

Budgeting/Controlling/Evaluating

Each of the seven elements of smart governance was studied in at least three articles in the reporting period of 2014–2019. Under "*norms*," a study on the governance of public–private partnerships found that long-term relationships might be better served by establishing "relational norms," which rely on transparency, risk sharing, collaboration including contract re-negotiations, rather than executing the stipulations in a previously signed contract to the iota even if the original assumptions and baselines no longer hold (Benítez-Ávila, Hartmann, Dewulf, & Henseler, 2018). Smart governance would, hence, find a balance between relational and contractual governance. In terms of "*policies*," the effect of outsourcing as a trademark New Public Management policy was found to be rather unsuccessful in shrinking the public sector in size or in curtailing government expenditures (Alonso, Clifton, & Díaz-Fuentes, 2015). However, from a smart governance perspective, other effects of outsourcing might be the results such as service improvements, workload reductions among others. With regard to "*practices,*" a study on the effectiveness and efficacy of funding for students' active commuting to schools along with the Safe Routes to School program showed that this kind of funding led to modest outcomes in terms of prespecified goals independent from the size of grant amounts (Hoelscher et al., 2016) suggesting that future (smarter) interventions might need to also consider other factors such as parents' influence. With respect to "*information*," one of the studies identified in this particular element portrayed the role of information sharing for successfully collaborating on complex budgeting issues (Chohan & Jacobs, 2017). As case in point the collaboration of the Congressional Budget Office with the White House when providing the groundwork in the context of shaping the Affordable Care Act was highlighted, which represented a smarter approach to governance and successful legislative process than observed in the previous failed attempts for such legislation. In terms of "*ICTs and Other Technologies*," a study investigated the potential role of information and communication technologies (ICTs) for providing information and transparency about budgeting and decision processes (Przeybilovicz, Cunha, & Póvoa, 2017). While ICTs provided access to the related information, without context, that is, without smart guidance, it was found, simply having access did not provide the expected transparency. Under "*Skills and Human Capital*," a study in the context of local government assessed the efficacy of trainings on interpersonal leadership skills and concluded that, while initially positive effects were measured, after less than a year after the training the skill levels would deplete (Getha-Taylor, Fowles, Silvia, & Merritt, 2015). Retraining, hence, would be necessary. Smart governance in this particular area would need to identify more long-term effective skill development and retention approaches. In terms of "*other resources,*" the involvement and active participation of communities in public budget planning has been portrayed as an effective and transparent process, which, however, might be limited in scalability due to resource scarcity (Kasdan & Markman, 2017). As the placeholder articles demonstrate, the seven elements of smart governance in the focus area of budgeting/controlling/evaluating are addressed by current research, although most articles make no explicit mention of the concept (see Table 2).

Table 2 Articles found per element

Elements of smart governance	Articles found (2014–2019)
Norms	7
Policies	3
Practices	4
Information	4
ICTs and other technologies	4
Skills and human capital	4
Other resources	3

Government Modernization

For "norms" of government operational streamlining and administrative modernization as a part of smart governance, a study found the key in gradually induced change of civil servants' values via training and retraining, which over time impact the norms and readiness for change for new ways of defining and performing given tasks and of internal and external collaboration (Schröter & Röber, 2015). With regard to "policies," the topic of "smart regulation" as an important aspect of smart governance was address in a study that investigated policies around low and zero carbon homes in the United Kingdom (Greenwood, Congreve, & King, 2017). The study emphasizes the need for private–public collaboration when it comes to adopting novel policies and "smart regulation" as in the case of LCZ homes and all what the authors call "substantive definitions of mandatory and non-mandatory standards with the outcomes sought" (p. 497). In terms of "practices," a 2015 study investigated citizens' use of government social media sites for measuring the impact of this particular access method for improving citizen engagement (Bonsón, Royo, & Ratkai, 2015). While overall engagement was moderate at best, social media sites that allowed for postings appeared to have a better reception. In regard of "information," a study compared the practices around the Freedom Of Information Act (FOIA) between the Bush and Obama administrations as an important pillar of transparency and, hence, smart governance (Wasike, 2016). The results were mixed with regard to "FOIA performance" (p. 425), although requests were found more speedily processed under the Obama administration. In terms of "ICTs and other technologies," a study inquired on civil servants' perceptions of the usability of new technologies and processes (Claver-Cortés, de Juana-Espinosa, & Valdes-Conca, 2017). The study found that due to the lack of staff training regarding the technological and infrastructural advances, the potential of the ICT-supported process improvements could not fully be realized. Under "skills and human capital," researchers studied the use of merit-based criteria for promotion to managerial levels in public administration and discovered improved performance levels (Cortázar, Fuenzalida, & Lafuente, 2016). With respect to "other resources," while New Public Management (NPM) and smart governance do not necessarily go hand in hand, a study on NPM implementation in Central Eastern European administration concludes that NPM instruments might help bring about "smart practices" in a reformed

Table 3 Articles found per element

Elements of Smart Governance	Articles found (2014–2019)
Norms	4
Policies	4
Practices	5
Information	4
ICTs and other technologies	4
Skills and human capital	3
Other resources	3

public administration (Dan & Pollitt, 2015). Taken altogether, the focus area of Government/Administrative Modernization and Process Streamlining has been well covered in recent academic research along all elements of smart governance (see Table 3).

Security and Safety

This is one of the few focus areas, where no academic contribution could be identified for one or two elements of smart governance, in this case with regard to "other resources." Furthermore, only one contribution was found for the element of "skills and human capital," indicating that these particular elements in the focus area of "safety and security" need more academic attention. In a thesis on the subject matter of "norms," Japan's potential normative security dilemma is portrayed (Dillard, 2017). The country constitutionally self-obligated itself to refrain from building and maintaining a large military apparatus and in the 1970s consequently signed and ratified the nonproliferation treaty to further assure her neighbors of its non-bellicose and peaceful-only intentions. While neighboring nations such as China, North Korea, and Russia have meanwhile built up sizable nuclear arsenals, which by their sheer existence present serious threats to the country, Japan has so far relied on the United States for nuclear deterrence. It remains to be seen, whether or not such norm of reliance on others in an existential matter of security is wise and can be maintained in the long term. A more robust military, which includes a credible nuclear capability, might change the current norm in favor of self-reliance in this premier security area. In terms of "policies," a study investigates and compares safety and security-related policies in two regions and metropolitan areas in the Southern United States and Southern Europe (Tulumello, 2017). The study finds different political traditions and perceptions to play major roles in explaining different policy approaches to addressing safety and security concerns, for example, if violence was seen as an external threat to a community rather than a community-internal problem. In the former case policies were mainly designed to fight and suppress symptoms, while in the latter case, policies attempted to address the deeper causes, which might have gone beyond the reach of the mere policing of the

Table 4 Articles found per element

Elements of Smart Governance	Articles found (2014–2019)
Norms	4
Policies	4
Practices	3
Information	3
ICTs and other technologies	4
Skills and human capital	1
Other resources	0

problem. With respect to "practices," the safety and security risks of "smart buildings" was the focus of a study (Wendzel, Tonejc, Kaur, & Kobekova, 2018), which reported on a number of successful recent cyberattacks on such building. The contribution discussed various practices and methods for protecting the buildings against such attacks. Regarding "information," a 2017 study proposes an integrated approach called "Systems-Theoretic Process Analysis" (STPA), in which a safety team and a security team have to perform the analysis from their respective viewpoints in an integrated fashion with the intended result of improved detection of conflicts and other constraints (D. Pereira, Hirata, Pagliares, & Nadjm-Tehrani, 2017). Under, "ICTs and other technologies," a 2018 study investigates safety and security concerns along with potential remedies regarding Internet of Things (IoT) devices, which play increasing roles in private households as well as businesses around the world. Unprotected or poorly protected IoT devices have so far introduced a myriad of vulnerabilities in countless homes and businesses, which may produce undesirable consequences if unaddressed (Bastos, Shackleton, & El-Moussa, 2018). In the only contribution found under "skills and human capital," a study on cyber-physical systems suggests that besides the technical aspects of such systems the social, process, and informational aspects deserve study, and in particular the engagement of relevant stakeholders (Törngren et al., 2017) (see Table 4).

Infrastructure Overhaul and Ubiquitous High-Speed Connectivity

This focus area was found less strongly covered than others, which was unexpected. While every element was covered, four of seven elements were only addressed by two studies. With regards to "norms," a study scrutinized the underlying principles, which finally helped foster a massive overhaul of the entire ICT infrastructure and its governance model of a major city government in Central Europe (Scholl & AlAwadhi, 2016a). In terms of "policies," a study looks at policy tradeoffs regarding infrastructure-related decisions in terms of temporal, regional, and sectoral complexities (Wegrich & Hammerschmid, 2017). Under "practices," another study

Table 5 Articles found per element

Elements of Smart Governance	Articles found (2014–2019)
Norms	2
Policies	3
Practices	2
Information	3
ICTs and other technologies	3
Skills and human capital	2
Other resources	2

investigates the evolving expectations and practices regarding energy consumption in ever expanding wireless and wired Internet and smartphone infrastructures, which became more demanding, but are also viewed as service opportunities (Wiig, 2016). With respect to "information," a study on the effects of ubiquitous smartphone connectivity found that among undesired outcomes and concerns, which need further assessment and study, are the lack of privacy protection and information overload (Gao, Liu, Guo, & Li, 2018). With regard to "ICTs and other technologies," another study discusses the implications of 5G technologies on the emergence of very fast and ubiquitous broadband infrastructures, which connect wireless and wired infrastructures allowing for cognitive objects and cyber-physical systems (CPSs) (Soldani & Manzalini, 2015). Under "skills and human capital," a study investigates to what extent medical and other care personnel can be supported and even replaced by advanced remote mobile sensor and monitoring systems, in particular in the context of a rapidly growing elderly population (Deen, 2015). In terms of "other resources," a study discusses the application areas of direct mobile-to-mobile communications (D2D), which takes advantage of the proximity of mobile devices (for example, in vehicle-to-vehicle communication) without using the wireless or cellular networks (Mumtaz, Huq, & Rodriguez, 2014) (see Table 5).

Electric Mobility

In this focus area, the smart governance element of "skills and human capital" is unrepresented since no study could be identified covering it. Under "norms," a study on the motivations or dislikes of potential buyers of electric cars included social norms (how socially well regarded and incentivized) as well as practical considerations such as range and recharging opportunities (Bobeth & Matthies, 2018). With respect to "policies," a study on adoption of "smart mobility" in Italian cities showed that little effects in terms of uptake could be shown unless policies directly subsidized and incentivized the adoption (Pinna, Masala, & Garau, 2017). Regarding "practices," along similar lines the evolution of practices regarding electrical vehicle charging infrastructures was analyzed in a study (Hall & Lutsey, 2017), which showed Norway and the Netherlands as the then current (early) leaders. When it comes to "information" in the context of electric mobility, a paper pointed out that

Table 6 Articles found per element

Elements of Smart Governance	Articles found (2014–2019)
Norms	3
Policies	3
Practices	3
Information	3
ICTs and other technologies	3
Skills and human capital	0
Other resources	3

electric vehicle recharging might lead to unwanted peaks, brownouts, and even blackouts unless properly balanced and managed (Kuran et al., 2015). Intelligent and information-based load and peak management in parking lot recharge scheduling might be an appropriate solution. With regard to “ICTs and Other Technologies,” a study finds strong interconnections and cross-benefits between the various major variables of fossil fuel-free energy production, changed patterns of energy consumption, and non-carbon emission based transportation systems and their orchestrated and coordinated transition into a new type of modern economy (Canzler, Engels, Rogge, Simon, & Wentland, 2017). In terms of “other resources,” a study focused on the vehicle-to-grid (V2G) capability of plug-in electric vehicles, whose batteries serve as a power storage, which enables such vehicles to release power back to the grid if the greed needed it (Shafie-Khah, Neyestani, Damavandi, Gil, & Catalão, 2016). So far, studies in this particular area have only produced mixed results due to the complex interplay of variables (see Table 6).

Participation and Collaboration

Like with Electric Mobility, so with Participation and Collaboration, the “skills and human capital” element cell remained empty, because no studies on the subject in this focus area could be identified. And, likewise again, for most other elements at least three studies were found. In terms of “norms,” a study compares select smart government and smart governance approaches in the PR China and in the West finding both bottom-up and top-down approaches in both (Lin, 2018). While some outcomes of these approaches appear similar, the basic and driving norms appear to be different. On “policies,” a 2017 study looked at the Open Government Partnership initiative and policy, which was geared at smart approaches to transparency and participation in a smart government and smart governance context, and concluded, that “the initiative had limited impact on the type of policies that were proposed and enacted. In sum, the OGP is an administrative reform that was launched with great fanfare, but limited influence in the US context” (Piotrowski, 2017, p. 155). With regard to “practices,” another study focused on public libraries’ “microblogging” practices such as Twitter-based blogs and found that such practices help both creating new and maintaining existing relationships with patrons (Cavanagh, 2016). In

Table 7 Articles found per element

Elements of Smart Governance	Articles found (2014–2019)
Norms	3
Policies	3
Practices	3
Information	3
ICTs and other technologies	3
Skills and human capital	0
Other resources	2

terms of "information," another study that investigated the informational content of participation and transparency-related microblogs found these to be "posted for self-promotion rather than service delivery" (Zheng & Zheng, 2014, p. S106). With respect to "ICTs and other technologies," a study found that smart governance initiatives overemphasized technologies and underemphasized human factors and other hard-to-quantify gains (Jiang, Geertman, & Witte, 2019). In regard to "other resources," a 2017 study on participation and co-creation of public value found enablers and barriers, some of which were known from previous studies; however, data and technology literacy along with other related capabilities were also identified as indispensable (Toots, McBride, Kalvet, & Krimmer, 2017) (see Table 7).

Open Data/Big Data Provision and Use

Also, in this smart governance focus area all elements were addressed by at least three studies. Under "norms," a study pointed at the increasing cultural diversity in metropolitan areas with serious implications for the management of cities based on open and big data, which help inform government managers' cultural intelligence as conceptually and practically directly connected to smart governance (Faraji, Nozar, & Arash, 2019). Regarding "policies," another study compared the open data policies of several countries, and based on the comparison compiled a set of detail policies, which the authors proposed to further consider (Nugroho, Zuiderwijk, Janssen, & de Jong, 2015). With respect to "practices," a 2016 study developed the notion of an open data ecosystem, in which producer, innovators, and users of the open data would both contribute and benefit from the government-enabled ecosystem (Dawes, Vidiasova, & Parkhimovich, 2016). In terms of "information," another 2016 study set out to measure the quality of government-released open data and information at regional and national levels and found the aggregated national data of higher quality than the regional data (Vetrò et al., 2016). "ICT and other technologies"used in this focus area were studied in the context of and aiming at social inclusion, which were found major enablers toward that end (McKenna, 2017). With regard to "skills and human capital," a 2015 study reported on local and neighborhood projects, which emphasized the human skills and relationships sides of open data initiatives (Oliveira & Campolargo, 2015). For "other resources," a 2014 report described the practical

Table 8 Articles found per element

Elements of Smart Governance	Articles found (2014–2019)
Norms	3
Policies	3
Practices	3
Information	3
ICTs and other technologies	3
Skills and human capital	3
Other resources	3

challenges when developing a linked open data instance, for example, based on the Resource Description Framework (RDF) for a legacy dataset such as the British National Library (Deliot, 2014) (see Table 8).

Open Government, Transparency, and Accountability

Like the previous focus areas, so is this one on open government, transparency, and accountability fully covered by research across all elements. Since the focus areas of open data and open government are closely related, quite a number of studies could have been listed in either area. However, some nuances and emphases still differ, which is why these two areas are kept apart despite quite the expectable overlap. Under "norms," a study concerned itself with the long-term costs that (open) government incurs when it provides open (and authoritative) data (Johnson, Sieber, Scassa, Stephens, & Robinson, 2017), so that norms and priorities along with purpose definitions for data provision and constituencies are needed. With regard to "policies," the overcoming of barriers to open government and open government data requires the formulation of policies, which extend over the barriers of access to those regarding uses, innovation, and value creation (Smith & Sandberg, 2018). In terms of "practices," a 2015 study attempted to assess to what extent open government portals such as data.gov serve the purposes of transparency and accountability (Lourenço, 2015). It concluded that these portals were mostly neither in structure nor organization conducive (enough) to purpose. Regarding "information," a 2015 literature review on academic publications on the subject found participation, transparency, and collaboration at the core of open government, all of which rest on access to information and enablement by modern ICTs (Wirtz & Birkmeyer, 2015), which leads to "ICTs and other technologies." In this regard, a 2018 study, which investigated the Chinese Social Credit System (SCS), warned that the benefit of "trust," which systems of this kind can provide in interactions and transactions, may come at the high cost of other perils such as social control and violations of human rights (Chen, Lin, & Liu, 2018). Under "skills and human capital," a 2016 paper investigates the role of human skills in communities allow for a bottom-up approach to open government-style urban planning (Alverti, Hadjimitsis, Kyriakidis, & Serraos, 2016). With respect to "other resources," open government and open data have also been linked to sustained commercial value creation. A 2016 study attempts to define guidelines for developing such ecosystem, in which the commercial value creation depends on the uninterrupted availability of open data (Zuiderwijk, Janssen, van de Kaa, & Poulis, 2016) (see Table 9).

In summary, as pointed out in the introduction to this section (RQ#1) of the findings, most elements in the Smart Governance Roadmap, were covered as illustrated in some details above. However, in three focus areas (safety and security, electric mobility, and participation and collaboration) the role and function of skills and human capital has remained unexplored by research. Furthermore, by virtue of using placeholders it has been attempted to illustrate where recent research has been directed, which provides some illumination and potential guidance for future research in these areas.

Ad *RQ#2* ("*What relationships of themes and topics are found inside the academic research on Smart Governance in the Public Sector, and what is their relative weight?"*)

While in the previous section a subsample was used to illustrate the directions of smart governance-related research across the Roadmap, in this section the whole sample was subjected to a bibliometric keyword analysis, which identifies the relationship of these keywords to each other forming themes and topical threads (represented by the number of occurrences and the total link strengths, see Table 10) that permeate the entire sample of literature on smart governance.

In the overall view of keywords and their relationships (Fig. 1), it is confirmed that "open data" is the by far most frequently occurring keyword in smart governance-related research (as was already shown in Table 1). However, in this overall overview it becomes also clear how close and how closely connected "open data" is to "big data," "open government," and "digital government." The keywords "smart governance" and "smart city" also appear central and strongly related to each other. The overall overview also allows for the inspection of keywords that are represented more peripherally than centrally in smart governance-related research. Among those more distal are keywords such as administrative reform, public sector reform, budget, public finance, stakeholders, smart grids, electric vehicles, electric mobility, sustainability, and policy analysis to name a few. Also, topics such as public finance, budgets, electric mobility, information, linked open data, and open data policies were addressed earlier, that is, in the 2015 timeframe, whereas newer topics

Table 9 Articles found per element

Elements of Smart Governance	Articles found (2014–2019)
Norms	3
Policies	3
Practices	3
Information	3
ICTs and other technologies	3
Skills and human capital	3
Other resources	3

Table 10 Top 25 keywords by occurrence and link strength

Rank	Keyword	Occurrences	Total link strength
1	Open data	34	26
2	Open government	15	14
3	Smart city	14	13
4	Public administration	12	10
5	Digital government	11	10
6	Big data	10	9
7	Participation	9	9
8	Transparency	9	7
9	Policy	9	6
10	Smart governance	8	8
11	Internet of things	7	3
12	Collaboration	6	5
13	Policy analysis	6	5
14	Electric mobility	6	3
15	Administrative reform	6	2
16	Innovation	5	5
17	Sustainability	5	3
18	Renewable energy	4	4
19	Smart government	4	4
20	Budget	4	3
21	Electric vehicles	4	3
22	Local government	4	3
23	Linked open data	4	1
24	Privacy	3	3
25	Control	3	3

(2016–2019) include policy, policy analysis, governance, and smart governance itself (see Fig. 1).

The VOSviewer analysis tool allows for representing keywords and their link strengths in a focused fashion, which then more prominently reveal the strongest links between the respective keywords. For example, if taking an "open data"-centric view (Fig. 2), the particular links come to the fore. The strongest links exist between "open data" at the center and "open government," "open data policies," "big data," "governance," "innovation," and "stakeholders." No strong, if any, links exist between "open data" at the center and, for example, "electric vehicles," "electric mobility," "administrative reform," "collaboration," "sustainability," and the "Internet of Things."

When the perspective is switched to an "open government"-centric one, as Fig. 3 shows the by far strongest link goes to "open data." Other strong links include "digital government," "public administration," "open data policies," "big data," and "collaboration." As a surprise, no strong links were found between "open government" at the center and "administrative reform," "public sector reform," "smart city,"

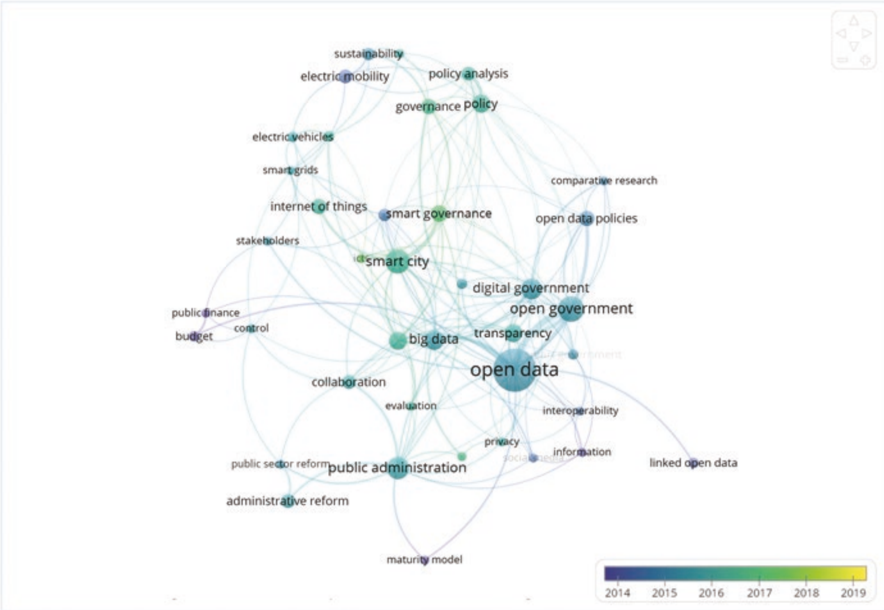

Fig. 1 Overall view of keyword occurrences and link strengths

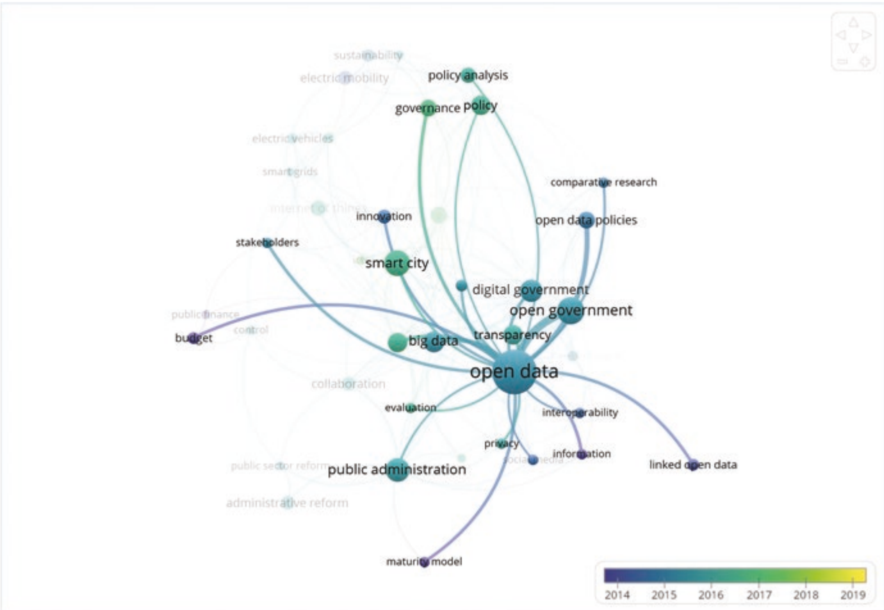

Fig. 2 Open data-centric perspective

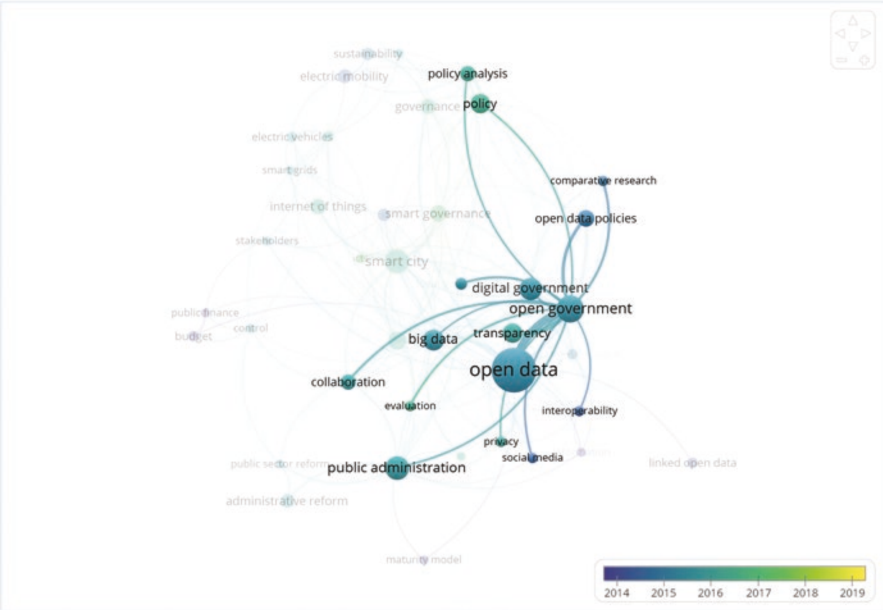

Fig. 3 Open government-centric perspective

“smart governance” (as a keyword), as well as topics such as “budget,” “public finance,” and “control.”

Upon taking a “smart city”-centric perspective (Fig. 4), the strongest and more recent links can be found to “smart governance” and the “Internet of Things.” Also, strong links exist between smart city at the center and “open data,” “smart grids,” “renewable energy,” “innovation,” “collaboration,” “digital government,” and “smart government.” Interestingly, no strong links were found between “smart city” at the center and keywords such as “administrative reform,” “public sector reform,” “electric vehicles,” “electric mobility,” “sustainability,” “transparency,” “interoperability,” and “open government” the latter of which can also be seen as surprising.

In summary, the frequency of occurrences of keywords provides another angle for looking at the most recent body of publications identified in the context of smart governance-focused research as laid out in the Roadmap. The top-three most frequent keywords in the sample of recent-years studies on smart governance were “open data,” “open government,” and “smart city.” For this second research question, the three top keywords and their respective links to other keywords were investigated. As the keyword-centric perspectives reveal, some of the most frequent keywords strongly connect with a certain number of other keywords, which form topical and thematic clusters inside the smart governance study space. Remarkably, some of the keywords do not strongly connect to some other keywords, which one might have expected to connect, for example, “open government” to “public finance,” or “smart city” to “electric mobility.”

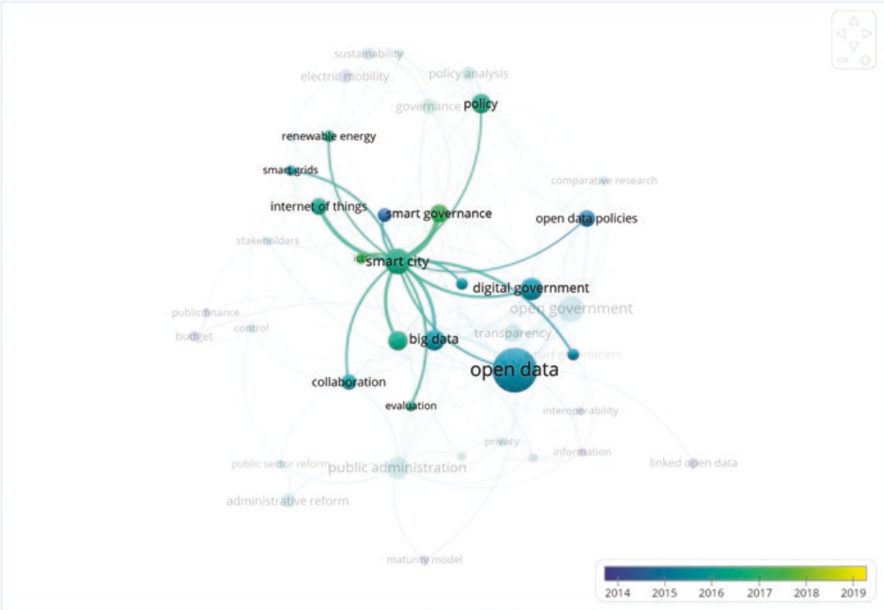

Fig. 4 Smart city-centric perspective

Discussion

General Observations and Limitations

In the context of RQ#1, while the review of the literature presented above is comprehensive with regard to covering, with one placeholder study each, the cells of the "Roadmap" that represent the intersection of focus areas and elements (see Table 1) it is important to emphasize that the coverage is deliberately non-exhaustive. Whereas in some instances only a single study could be identified for a given cell, in other instances double-digit numbers of studies were found. Forasmuch as the chosen placeholder approach limits the overall generalizability of the review results, it nevertheless allows for an assessment of coverage and resulting usefulness of the Roadmap for research and practice as well as for an initial overview of research directions across the topical span of the roadmap, which was the object of this research. If the entire Roadmap was used for organizing a comprehensive and exhaustive review across the topical spectrum, the researcher would quickly realize that she or he dealt with a rapidly expanding and fast-moving target. Therefore, for reasons of the sheer quantity of continuously emerging new studies, in-depth reviews that attempt to capture at least the lion's share of relevant contributions at a given point in time will be more practical, manageable, and meaningful when targeted at only a single focus area across all elements, or on one or two adjacent elements (for example, norms and policies) across all focus areas. Despite these limitations, when inspecting the findings for each of the seven elements of smart governance across the eight areas of focus, several observations are made and some interesting details emerge. In the following the findings regarding RQ#1 are discussed for each element of the Smart Governance Roadmap.

Norms in Smart Governance Initiatives

Among the norms of smart governance initiatives emphasized in several focus areas were stakeholder inclusion as a prerequisite for transparency, both of which seen as serving as the foundation of long-term relationships and collaboration. Purpose and priority definitions were also considered normative prerequisites in smart governance initiatives. Depending on geography, cultural, and historical context, different normative approaches to smart governance were found ranging from bottom-up to top-down and blends of the two approaches, all of which appear in need of inclusion and "cultural intelligence," as one paper stated.

Smart Governance-Related Policies

Echoing the notion of stakeholder inclusion as a norm discussed before it was again emphasized in the context of formulating novel smart governance policies. Smart governance policies were shown to differ quite markedly depending on stakeholders' basic assumptions suggesting that a discourse about those assumptions might be necessary at the outset. Smart governance policies need to be designed for overcoming initial barriers, for example, by providing incentives, but might also incorporate time, regional, and sectoral tradeoffs. As with in the case of norms, geographical, historical, and cultural differences lead to a variety of smart governance-related policies.

Smart Governance-Related Practices

While policies might have provided monetary and other material incentives, that notwithstanding cases that did not yield the intended outcomes were reported suggesting that other influencing factors also need consideration. Other smart governance practices included the effective shielding of smart infrastructures against cyberattacks, bringing to the fore that high-speed wireless and wired infrastructures were not only enablers of smart governance practices but rather also their potential Achilles' heels, for example, in terms breaches of privacy and additional novel vulnerabilities. Smart governance practices appeared to have evolved faster when the necessary upfront and ongoing investments were made. While open data practices demonstrated quite a number of effective private–public service co-productions, the overall approach to smart governance practices including government portals and social media use appeared to be missing in consistency and maintainability (also in terms of stakeholder relationship creation and maintenance).

Smart Governance-Related Information

Information sharing was portrayed as important capstone to smart governance in a number of studies, in particular, with regard to transparency, participation, and collaboration. It was likewise seen as effective means for discovering conflicts and constraints in safety and security-related efforts. On the downside, information sharing was also found in a number of situations to lead to information overload at the receiving end. Furthermore, information flooding was also part of the aforementioned problem of privacy breaches. In some cases, information sharing was found to have pro-cyclical effects exacerbating peak load problems, for example, in EV recharging.

ICTs/Other Technologies and Smart Governance

Interestingly, the studies presented somewhat mixed results regarding the observed impacts and desired effects of ICTs and other technologies. On the one hand, while they were generally seen as fundamental enablers of new ways of smart interactions and smart transactions, users rated several new systems not superior to their predecessor systems. Furthermore, IoT devices were seen critically for introducing novel vulnerabilities. On the other hand, high-speed 5G-infrastructure were also understood as foundations for "intelligent" cognitive objects and cyber-physical systems, which were seen as critical building blocks for a carbon-free new economy. Some studies suggested that too much emphasis was put on novel ICTs and their capabilities at the expense of understanding and factoring in the human factors. Finally, the Chinese Social Credit System (CSCS) has been discussed as a comprehensive system for enabling trust and credibility among parties that do not know each other. The perils of such systems were seen in the potential of social control and government surveillance.

Skills and Human Capital and Smart Governance

As mentioned above, skills and human capital was the element in the "Roadmap," for which the least studies could be identified across the eight focus areas. Skills and human capital are fleeting and moveable properties, which are not owned by an organization, and which cannot be stored and managed in a fashion like fixed assets. However, merit-based rather than seniority-based promotions appear to better suit a smart governance regime. As another study showed though, training, re-training, and skill development investments were found relatively ineffective because of their quick depreciation over time and the low rate of retention. This phenomenon along with stakeholder involvement appears to be understudied in the context of smart governance.

Other Resources and Smart Governance

Under this particular rubric fairly diverse topics were studied reaching from types of community involvement to the use of instruments known from New Public Management for the purpose of smart governance. Furthermore, integrating legacy systems and their data into the overall scheme of smart governance was studied as well as new methods of directly connecting smart devices (D2D) along with smart-grid balance and management topics.

In summary, using the 2014 "Roadmap" for categorizing, analyzing, and reviewing the academic literature published in the 5 years after the Roadmap's publication provides a comprehensive overview of focus areas and smart governance elements covered in academic research for that period of time. From that perspective, the Roadmap can be said to have served as a potent hindsight analysis tool. With regard to understudied areas, this analysis furthermore shows that additional research is needed in the areas of skills and human capital as they relate to the establishment and development of smart governance.

Themes and Topics across Smart Governance Research

Regarding the findings in the context of RQ#2, the keyword frequency and link strengths analysis provided additional and important insights regarding the structure and major components of smart governance-related research as represented in the sample. It is important to distinguish that while the findings under RQ#1 were based on the subsample of over 50 placeholder studies, the VOSviewer-based analysis included the entire sample of 171 studies. However, even though the sample size is much larger in this regard, for all the reasons elaborated above, it would not be justifiable to generalize the results garnered from analyzing this larger sample. That notwithstanding, certain focus area and element-permeating themes and topics along with their relative weights and linkage strengths could be identified. So far, within and across the aforementioned focus areas and elements, smart governance research has revolved around nine major, that is, most frequent keywords and concepts (in this order) (a) open data, (b) open government, (c) smart city, (d) public administration, (e) digital government, (f) big data, (g) participation, (h) transparency, and (i) policy. When analyzing the top-three keywords in research and their relationships to other keywords, a more detailed and refined picture emerges, which also informs the discussion on the focus areas and smart governance elements discussed before. Some topics (keywords, themes) appear to be more closely related to others, while disconnected from yet others. As case in point for the latter, the missing connection between “open government” and “administrative reform” shows that a holistic understanding of the smart governance concept is still in an early evolutionary phase. Similar non-existing links were found elsewhere. While one can argue that the strong foci on certain research areas may have prevented the establishment of some (almost intuitively obvious) links to other adjacent areas, much research reported on in this chapter upon its initiation was conducted without a clear directional sense or a roadmap of the overall topic in mind, which is just how research unfolds in pursuit of a new topic in the early stages.

Concluding Remarks and Future Research

It has been the object of this chapter to investigate to what extent the research on smart governance was informed by or can be categorized in hindsight by the proposed 2014 “Roadmap” for study and practice (Scholl & Scholl, 2014). Furthermore, this chapter intended to establish the major themes and topics in the study of smart governance and their interconnections.

While despite quite a number of citations the “Roadmap” article of 2014 has not directly “guided” identified research on the subject in the subsequent 5 years, it can nevertheless be invoked for hindsight analyses of where research has been directed. Interestingly, the vast majority of topical elements of smart governance proposed in the “Roadmap” were found covered to at least some extent. The roadmap appears robust in terms of the eight focus areas, although some areas might be revised (for example, “electric mobility” to “emission-free mobility”). Likewise, the elements of smart governance (infrastructure) defined by Johnston & Hansen in 2011 appear to have stood the test of time (Johnston & Hansen, 2011).

The here presented cross-cutting topics/themes analysis might further inform researchers regarding important connections and linkages to be considered in future research.

Future empirical research might benefit from referencing itself regarding the “Roadmap,” since it makes transparent where exactly research on the subject is targeted, and what likely connections might exist. In any case, as a (very reluctant) producer of “frameworks” and “roadmaps” himself, this student of smart governance and other digital government topics urges his colleagues to gracefully abstain from presenting more “conceptual,” “theoretical,” and otherwise high-flying constructs, if there is no immediate intention to follow through and no later evidence of having followed through with future empirical research based on such frames.

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Path Dependency of Smart Cities: How Technological and Social Legacies Condition Smart City Development

Albert Meijer and Marcel Thaens

Abstract This chapter develops a theoretical perspective on the path dependency of smart cities. Our perspective will highlight both the physical and social dimensions of path dependency and also reflect on their interrelations. We will present a case study of the city of Rotterdam in the Netherlands to show the value of this perspective on the smart city. The empirical analysis highlights the importance of *technological and social legacies*. The research shows how an innovation program called the Glass River Maas formed an essential information infrastructure for further developing smart city projects (technological legacy). In addition, we identify certain networks of innovators that started to collaborate on earlier projects and now form the driving force behind current smart city developments in the city of Rotterdam (social legacy). This chapter concludes that smart city choices can be understood on the basis of a historical analysis and therefore challenges the dominant assumption that the smart city is something totally new. We conclude that more comparative work is needed to understand the different smart city trajectories as evolving from technological infrastructures that were constructed in the past and social networks that were developed in earlier collaborations. Understanding the past of the city is crucial to understanding how its future is currently being shaped.

Keywords Smart city projects · Technological legacy · Smart city technological infrastructure · Smart city social networks · Smart city case study

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_2

Introduction

The idea of a smart city guides the work of urban planners around the world in their efforts to improve the problem-solving capacities of current (and new) cities. The basic promise is that new technologies will help to tackle wicked problems such as congestion, air quality, and urban safety by proving more information and new options for coordinating actions. The promise of the smart city—as propagated by big companies and high tech gurus—is a technological answer to social problems. The basic notion is that better data about urban issues—'reading the city'—can result in better knowledge about urban dynamics—'processing the city' and thus form the basis for more effective interventions in these dynamics—'steering the city'. This 'computational logic' of urban governance has gained widespread momentum and provides the basis for projects focusing on urban mobility, urban safety, urban energy, etc.

This technological turn in urban governance has not gone unnoticed in the academic community. Academics in a variety of disciplines have started to investigate smart cities from a conceptual but also an empirical perspective. Even though there is quite some discussion on definitions and conceptualizations, most papers about smart cities highlight that they constitute a radical change that consists of the use of new technologies, in new collaborations to realize a new vision for the city (Meijer & Bolívar, 2016). Throughout the past two decades, however, three types of academic analyses of the smart city have been presented in the literature.

The first wave of techno-optimistic papers about smart cities suggested that urban problems around the world are quite similar and that the use of new technologies for urban management presented (Lee, Phaal, & Lee, 2013; Odendaal, 2003; Walravens, 2012). Many of these papers were written by academics with a background in information technology and, seemingly, little knowledge about the dynamics of cities and high confidence in the power of new technologies to deliver upon their promise. The analyses focus mostly on how to implement the new technologies and which preconditions need to be fulfilled to make this implementation to a success.

The second wave of papers about smart cities unmasked these techno-optimistic visions as neoliberal positions that, under the disguise of technological advancement, try to capture the urban dynamics from the perspective of the market (Greenfield, 2013; Grossi & Pianezzi, 2017; Hollands, 2008). Various critical authors from the geo-sciences stressed that the techno-optimistic papers paid little or no attention to the role of citizens, contextual differences, power play, framing, etc. These publications often radically argue 'against the smart city'—the title of Adam Greenfield's (2013) insightful analysis—and stress that we need to argue against this dangerous discourse.

The third wave of papers on smart cities develops a perspective on smart cities based on a socio-technical understanding of these developments (Carvalho, 2015; Kitchin, 2014). Academics from Science and Technology Studies are dominant in this line of research and the choices of smart cities are studied on the basis of institutional rules (Raven et al., 2017), stakeholder engagement, physical context, and political dominance. The objective of these approaches is to develop a contextual understanding of smart city dynamics based on a study of the interactions between the various actors in a specific institutional setting. The dominant message is that a smart city may be a good idea but only if it is based on a sophisticated, contextual socio-technical understanding of the smart city and if it is embedded in democratic forms of decision-making.

This chapter aims to contribute to this third wave of publications by bringing in a perspective that until now has received limited attention: path dependency. Contextual studies of smart cities result in interesting findings but tend to ignore (1) that the fact that smart city technologies generally build upon existing physical infrastructures and (2) that networks of actors working on smart cities often build upon earlier collaborations. A smart city, in short, can also be studied from the perspective of path dependency (Cowan, 1990; Pierson, 2000): earlier situations condition the way current choices are being made.

The ambition of this chapter is to develop a historical institutionalist perspective on smart cities that helps us to develop a better understanding of the differences between the playing fields in which actors in different smart cities operate. How does the pathway of the smart city condition current options? We will use the literature on path dependency to develop a historical institutionalist framework for smart cities and highlight the value of this framework through an illustrative case study.

Path Dependency of Smart Cities

Many analyses of smart cities emphasize the newness and the disruptive nature of these technologies. The technologies are said to radically change the way the city is perceived and steered by bringing in new forms of monitoring, new forms of data analyses, new visualization technologies, etc. At the same time, from work on large technological systems, we know that new technologies are never introduced into a vacuum. The existing infrastructure, hardware, software and data of organizations form an important context for the introduction of new technologies. This means that we need to zoom out and consider how this context was formed to understanding how the context conditions the opportunities and limitations for introduction new smart city technologies. The perspective of path dependency is most helpful for providing this broader perspective.

The approach of path dependency fits in the theoretical frame that is referred to as historical institutionalism (Hall & Taylor, 1996). This approach is built upon the notion that social causation that is 'path dependent' which means that contextual features of a given situation inherited from the past condition current operative forces. This effectively means that the same operative forces can have different outcomes in different situations because these situations were shaped by their specific historical trajectory. Historical institutionalism stresses that institutions are seen as relatively persistent features of the historical landscape and central factors pushing historical development along a set of 'paths'.

Even though the path dependency perspective has not yet been applied to the smart city, the path dependency perspective in political science is well established (Pierson, 2000). In general, the path dependency perspective stresses that the options for decisions in the present are limited by the decisions have been made in the even though past circumstances may no longer be relevant. The classic example of path dependency is the monarchy that we still have in many European states. The monarchy is certainly not an option for democratic governance that we would select now but the options to change our form of governance are conditioned by the fact that in the past a monarchy was created. Similar analyses have been applied to a variety of political institutions.

The same logic of path dependence has also been applied in the study of technology. The various studies of the history of technology highlight countless examples and the QWERTY-keyboard is probably the most famous one (David, 1985; Noyes, 1983). These studies highlight that the current logic of computer keyboards provides no rationale for a QWERTY-keyboard but studies suggest that the earlier logic of a mechanical typewriter demanded a keyboard that would not result in blockages. At the same time, all the training programs are now focused on the QWERTY-keyboard and therefore the switching costs of moving to another, probably more efficient, keyboard are too high and we keep on using the QWERTY-keyboard. Therefore, just like the monarchy, the QWERTY-keyboard is still an important part of our life.

Smart cities introduce new technologies to the city but also build upon existing structures that condition choices. These existing structures are both social—similar to the monarchy—and technological—similar to the QWERTY-keyboard. A path dependence perspective on smart cities therefore needs to highlight both the physical and social dimensions of path dependency and also reflect on their interrelations. Therefore, we have developed a framework which build upon theories of historical institutionalism from political science and sociology (Hall & Taylor, 1996) but also technology and technological systems from STS studies (Bijker, Hughes, & Pinch, 1987; Cowan, 1990; Hughes, 1989). The term 'lock in' is often used to discuss how paths of development limit choices but we prefer to use the more open concept of the 'legacy'. Central to this framework is the concept of the legacy which we define as a structure that results from the past but still plays a key role. On the basis of this literature, we propose that the path dependency should be analyzed from two, interconnected perspectives:

- *Technological legacies*. Technological choices in the past condition choices about new technologies. The developments of a railway infrastructure, for example, influences subsequent choices about transport. Translating this to the topic of this chapter, this means that ICT-infrastructures such as fast speed networks also condition the options for smart city technologies.
- *Social legacies*. Social choices and experiences in the past result in formal and informal social structures that condition our choices. Well-known examples are

the role of kings in European democracies and the theatrical appearance of judges in courts all around the world. These are social structures that we would not develop now but that remain to exist because of the historical embedding.

Our perspective highlights that these two components are interconnected in socio-technical pathways: social and technological features interact to generate specific routes in the developments of new technologies (Bijker et al., 1987). A purely economic perspective highlights that impact of these pathways on choice options and switching costs. Sociological perspectives, however, also stress that these pathways influence the framing of issues at cognitive levels. An institutional perspective stresses that the structures embed values and power and therefore the introduction of new technologies is never only about functional issues but also about social transformation.

The relevance of this framework is that it means that previous socio-technical pathways of cities influence current framing of smart city options and policies developed to enhance the smartness of cities. It helps us to challenge the idea—Smart City Out Of A Box—that cities around the world can use the same technologies to tackle challenges in a similar way. Every city is unique in tot only its physical features but also its history. The specific contextual nature of smart city developments can be understood by broadening up the analysis to earlier choices regarding both the technological and social structure of technological infrastructures. We will explore the relevance for this argument by exploring how a specific socio-technical pathways conditions current debates about smart city strategies in the Dutch city of Rotterdam.

Research Methods

An in-depth single case study is used to illustrate how path dependence influences the construction of the smart city. We will present a case study of the city of Rotterdam in the Netherlands to show the value of this perspective for understanding the dynamics of the smart city. The case study specifically focuses on the development of an open glass fiber network called the Glass Maas River through a public–private partnership (PPS) and the way this infrastructure influences subsequent discussions, actions and decisions about the future of Rotterdam as a smart city.

The city of Rotterdam is the second largest city in the Netherlands with a population of more than 630.000 inhabitants. The city is mostly known for its port: its port was formerly the largest port in the world and is still the largest port in Europe. The port is well connected to distribution systems such as rail and roads and this key focus on transport have earned Rotterdam the nickname ‘Gateway to Europe’. As the employment in the port is declining, the city is in the process of making a transition to an economy that is based on more knowledge-intensive activities such as healthcare and design. The smart city strategies of the city can thus be positioned in the context of both the old ambitions—transport—and the new ambitions—healthcare and design.

The city of Rotterdam has developed a variety of smart city initiatives. Key examples are the use of sensor networks for maintenance of objects in public space,[1] a digital twin city[2] and the knowledge hub urban big data.[3] At the same time, they have no overarching, integrated smart city strategy for the city. For our case study into the path dependency of smart cities, we chose to analyze how the development of a glass fiber network that started 15 years ago influences recent debates about the development of an integrated smart city strategy. The analysis aimed to reconstruct how an infrastructure that was created before conditioned current debates about a smart city strategy.

A key activity for upgrading the knowledge infrastructure of the city was the Glass Maas River Project. This project started in 2005 and continued until 2012. The main objective of the project was to develop a future-proof ICT-infrastructure as a precondition for strategic projects in the city. The project resulted in various outputs such as a glass fiber network in certain areas, the realization of a data center, the realization of the Rotterdam Internet eXchange, a start-up accelerator (Rotterdam Internet Valley), Rotterdam Wireless as a testbed for countless initiatives and various other projects and initiatives. The program ended in 2012 and certain initiatives such as the Data Center and the Rotterdam Internet eXchange were sold. A private company explores the glass fiber network on behalf of the city of Rotterdam. Finally, the foundation CoDE Rotterdam was created with the money from the sale of these initiatives to contribute to further technological developments in the city of Rotterdam.

Separately, but also connected as this case study will show, the city of Rotterdam has started to develop plans and strategies to become a smart city. These plans are less concrete and more at the strategic level but they provide the basis for a variety of other initiatives. An explorative investigation into the perspectives and preferences of the various stakeholders in the city was conducted in 2014 and 2015.

This single case study is based on two research projects.

- *Project 1: the development of the Glass Maas River*. In-depth interviews were conducted with 15 respondents. Respondents were selected from the city of Rotterdam and from entrepreneurs. The selection criterium we used was the basis of their knowledge about and involvement in the development of the Glass Maas River. In addition, relevant (policy) documents were analyzed.
- *Project 2: the potential of Rotterdam as a smart city*. A series of 33 in-depth interviews was conducted with various stakeholders and experts in the city of Rotterdam to identify the potential of smart city technologies for this city. The

[1] https://www.rotterdam.nl/werken-leren/assetmanagement/2018-05-30-Smart-city-sensoren-in-het-risicogestuurd-beheer.pdf.

[2] https://eu-smartcities.eu/news/rotterdams-digital-twin-redefines-our-physical-digital-social-worlds.

[3] http://urbanbigdata.nl/.

selection criterium we used was their knowledge about and stake in the development of Rotterdam as a smart city.

We used a standardized list of topics for these interviews and analyzed the outcomes qualitatively on the basis of the framework that we had developed for the historical institutionalist analysis of smart cities.

Findings

Glass Maas River Program[4]

The city of Rotterdam started the Glass Maas River Project in 2005 with a variety of stakeholders in the city and the program ran till 2012. The objective of the program was to develop a future-proof ICT-infrastructure as a necessary precondition for a variety of strategic projects in Rotterdam. The basic ambition was to realize an innovative ICT-sector by providing a glass fiber infrastructure, ICT-facilities and new services. A variety of projects was realized within this program:

- A glass fiber network was realized by the city of Rotterdam and the Glass Maas River Program was responsible for the construction, maintenance and exploitation;
- A network has been launched for innovative communications with citizens in Rotterdam (City Media);
- Rotterdam Wireless became operational as a testbed for a variety of applications;
- A Rotterdam Fiberlab Conference was organized to raise attention for all the ICT and glass fiber initiatives in the city;
- A variety of smaller and larger activities that use the glass fiber network have been developed and implemented;
- A data center—the Spanish Cube—was realized;
- A platform for exchanging knowledge and experiences within the ICT-sector—Rotterdam Fiber Glass—was initiated;
- Many next generation projects were started that focus on the continuing innovation of the infrastructure;
- The Rotterdam Internet Exchange—a key player in new technological developments and for the acceleration of start-up companies—was founded.

Participants in the Glass Maas River Program highlight that the value of the program lies in realizing a basic and relatively low cost ICT-infrastructure and providing a platform for a variety of other innovative activities. In addition, they emphasized

[4] The outline of this program is provided on basis of interviews with 15 respondents. The analysis focuses on factual features and shared perceptions and therefore no analysis of individual perceptions of the respondents is presented.

that it contributed to raising awareness in the city about the potential of ICT and providing a positive climate for high tech start-ups. They emphasize that the management of the variety of interactions between stakeholders by the city was key to its success. The city managed to stimulate the collaboration but also provide room for the other stakeholders. Creating a team spirit based on a clear vision and raising enthusiasm were crucial and were combined with a pragmatic approach to tackling problems.

The project ended in 2012 and key activities have been sold—such as the Data Center and the Rotterdam Internet Exchange—or positioned in another organization—the glass fiber network is now managed by a company that is fully owned by the city of Rotterdam. The money that was gained by selling the Data Center and the Rotterdam Internet Exchange was used to start a specific fund for stimulating ICT-developments in the city.

Toward a Smart City Strategy for Rotterdam[5]

In 2014 and 2015, the city of Rotterdam asked us as researchers to explore what the contours could be of a smart city strategy for the city of Rotterdam. For this research, we conducted interviews with a wide variety of stakeholders and this enabled us to provide an overview of the shared perspectives on the future of Rotterdam as a smart city. We will present these shared perspectives in this section and then we will analyze how these are related to the Glass Maas River Program that had already ended.

The respondents highlight that there is much potential but also an urgency to develop a strong vision on Smart City Rotterdam as a basis for more coherence between the variety of projects and initiatives. Political commitment is seen as crucial for the further development and realization of a smart city strategy. The shared vision for the development of Rotterdam as a smart city can be summarized in the following features:

- Rotterdam has the potential to become a smart city because of its political ambition, collaboration between stakeholders, technological infrastructure, economic basis, and attractiveness for international actors.
- Support for realizing Smart City Rotterdam is high both among externa actors as within the various departments of the municipal organization.
- The main challenge for Rotterdam is to generate more cohesion in the variety of initiatives in the city.
- Cohesion can be realized through an overall vision, political commitment, a structure for collaboration, a responsible unit within the municipal organization, and a smart city roadmap for the next years.

[5] The shared perceptions are based on 33 interviews with a wide variety of stakeholders. Again, our analysis will not focus on individual differences but on shared perceptions.

These main features are hardly surprising and could be formulated for many cities around the world. However, the specific actions to be taken to realize Smart City Rotterdam highlight the influence of the past. The perceptions of a strategy for Smart City Rotterdam emphasize the importance of building upon existing strengths of the city. The following suggestions for building upon existing strengths are highlighted by the various respondents:

- The technological infrastructure is of high quality and forms a key asset for the city. The vision document specifically refers to the glass fiber network, the Rotterdam Internet Exchange, and the Rotterdam Data Centers. The respondents indicated that this infrastructure needs to be extended and strengthened to realize a strong infrastructure for the smart city.
- The respondents refer to the existing (informal) networks between stakeholders as a 'coalition of stars'. There is much enthusiasm in the city and a high willingness to collaborate with other actors on new technological developments. At the same time, the respondents highlight that it the synergy between the variety of initiatives needs to be strengthened.

These perspectives on building upon existing strengths highlight ore specific features of Rotterdam. These features result from historical pathways and, as the next section will show, they can be connected quite directly to the Glass Maas River Program.

Analysis

The description of the Glass River Maas Program highlights the variety of activities and diversity of stakeholders involved in the program. In our analysis, we focused on identifying the legacies that resulted from the program and that condition current smart city choices. In the findings, we identified the two types of legacy that were expected on the basis of the literature: the technological and the social legacy. Our analysis of the opinions on a smart city strategy shows that the impact of these legacies was visible in the perspectives on further development of Rotterdam as a smart city.

The *technological legacy* consists primarily of the fiberglass network but in addition various other technological elements that conditions further choices were identified such as the wireless network and the data center. The empirical analysis highlights how the Glass River Maas forms an essential information infrastructure for further developing smart city projects. In the perspectives on a smart city strategy for Rotterdam, ICT-infrastructure was regarded as a starting point for new applications. The Glass Maas River Network forms an enabler for various forms of collaboration between public and private actors in the smart city. At the same time, this network only offers advantages to the users that are at a short distance from the network. This infrastructure is therefore more suitable for collaborations between companies and governments that for direct citizen engagement.

The *social legacy* consisted of the variety of formal and informal structures between actors in the city that had been created by the Glass Rover Maas Program. We identified networks of innovators that started to collaborate on earlier projects and now form the driving force behind current smart city developments in the city of Rotterdam. We found that in perspectives on a smart city strategy for Rotterdam, these informal networks are seen as a basis for more formal collaboration. The exploration of the potential of Rotterdam as a smart city highlighted the need for strategic structure for collaboration. This strategic structure can be developed on the foundations of the informal networks and various collaborations that have already been established. Many of these networks and collaborations have their origins in the Glass Maas River Project. A specific type of social legacy was the creation of an actor for investing in smart city projects. Some elements of the Glass River Maas—the Data Center and the Internet Exchange—were sold to the market and the money was used to create a nonprofit organization for the future development of technologies in the city of Rotterdam: the CoDE Rotterdam. In the perspectives on a strategy for smart city Rotterdam, the availability of dedicated funding for technological development played a (limited) role. The availability of extra resources from CoDE Rotterdam forms a facilitator for the development of innovative projects.

In addition, many elements were mentioned that were not or hardly related to the legacy of the Glass Maas River Project such as a smart port and a focus on the connection with the Rotterdam port. In that sense, the smart city strategy was much broader then the Glass Maas River with its specific focus on the value of ICT-infrastructures for the development of the city.

Conclusions

This chapter shows that the development of a smart city strategy can be understood on the basis of a historical analysis. This chapter therefore challenges the dominant assumption that the smart city is something totally new and radically breaks with previous solutions. Our research specifically identified the relevance of not only the technological legacy—i.e., the nature of technological infrastructures that facilitates new smart city applications—but also of the social legacy—i.e., the mutual trust and willingness to collaborate on innovative solutions and project in the city and the creation of dedicated actors to stimulate new technological developments.

The perspective of path dependence helps to open up the black box of context. Context is often either mystified—'each city is different'—or reduced to a set of variables that are supposed to characterize all the main features of the city (e.g., political system, size, location, prosperity). The path dependence perspective helps to conceptualize the uniqueness of the city without mystifying it. The path dependence perspective helps us to zoom out on the history of the city to position current conditions. Understanding the past of the city is crucial to understanding how its future is currently being shaped.

Our research provides a new basis for the growing acknowledgment that each city needs to develop its own understanding of what it means to be a smart city. Approaches from other cities cannot be copied because of differences in historical trajectories that have resulted in different technological and social structures. This also means that we need to approach current strategies for smart city developments as the choice for pathways that condition future options. A consideration of the pathways that are chosen needs to take future developments into account and not only direct outcomes.

Our in-depth case study provided rich information about the city of Rotterdam. A next step would be to analyze how the conditions for smart city strategies in Rotterdam differ from other cities. We conclude that more comparative work is needed to understand the different smart city trajectories as evolving from technological infrastructures that were constructed in the past and social networks that were developed in earlier collaborations. It provides a new angle for comparative research since it shows the importance of understanding historical trajectories.

Another issue for further research is whether legacies stimulate or hamper smart city developments. In the case of Rotterdam, the legacies seem to provide a strong basis for subsequent smart city activities but one can also imagine that legacies—for example related to outdated technology or ineffective institutions can hamper the realization of a smart city. Additional research is needed to identify when a legacy stimulates further developments or when it provides as 'dead-end road' for smart city development.

This chapter highlights that our studies of smart cities have been focusing too much on understanding current and future situations and too little on understanding the past. By highlighting the unique and disruptive nature of smart cities, the disconnect with the past is emphasized. This disconnect, however, does not acknowledge that physical and social structures indeed condition our current options and that we need to study the past to understand the future of cities.

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Government Characteristics to Achieve Smart Urban Governance: From Internal to External Transformation

Erico Przeybilovicz and Maria Alexandra Cunha

Abstract This chapter provides an overview of the government characteristics relevant to smart urban governance. A systematic literature review was conducted and merged with the existing e-government literature on critical success factors for adopting IT in the public sector. Identifying the government characteristics of smart governance sheds light on key organizational attributes that can pave the way for the transition from government to smart urban governance. The qualitative analysis of 96 articles on the governance of smart cities identified three main characteristics. The first is local government governance, related to the nature of the relationship among individuals, interest groups, institutions, and government. The second is government assets, which we believe are useful for providing support to smart urban governance in the form of funding, technology, and human capital. The third includes local government management, involving elements of strategy and the positioning of local public administration. Compared to literature in e-government, the governmental characteristics are quite similar, however, the focus of e-government is to transform the organization internally, while in smart urban governance literature, the focus is to transform both internally and externally. Future research should focus on understanding how governments could develop organizational capabilities to achieve internal and external transformation.

Keywords Smart city · Smart urban governance · Government characteristics · Governance · Assets · Management

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_3

Introduction

The governance of smart cities or smart urban governance involves the use of new digital technologies (ICTs)—social media, the Internet, open data, citizen sensors, and other ICTs—to strengthen the collaboration between citizens and local urban governments (Castelnovo, Misuraca, & Savoldelli, 2015; Tomor, Meijer, Michels, & Geertman, 2019). Many aspects are influencing both organizational settings and organizational management capacities, including, but not limited to, leadership, design strategies (including institutional arrangements), the capabilities of a local government, laws, regulations, and norms (Nam & Pardo, 2011; Ramon Gil-Garcia, Pardo, & Nam, 2015). These government characteristics have been broadly studied in many different academic fields, such as public administration, organizational studies and e-government (Liang, Qi, Wei, & Chen, 2017). However, at the same time, the term *smart cities* has started dominating debates in many research areas and understanding the government characteristics in this new context poses an avenue of interest.

Urban governments face challenges to guarantee urban prosperity and city livability, as over 50% of the world's population lives in urban contexts, and half of these people still live in poor areas (Castelnovo et al., 2015). Consequently, providing urban services, such as public health, education, public safety, and simultaneously improving sustainability and social inclusion for all its citizens has became a crucial issue. This is especially true in times of financial crises when traditional governance approaches are said to have fallen short and innovative solutions to tackle these challenges are necessary. The rapid development of new ICTs promises to transform urban governance into smart urban governance because they enable cities to creatively engage stakeholders in an open ecosystem for innovation and encourage social participation to find solutions for the city's problems. New digital technologies promise "smart governance" when integrated into citizenship participation strategies. However, smart urban governance is complex, involving collaboration among a variety of players and technologies. Depending on the local context, smart urban governance can produce different results requiring the local government to be endowed with some organizational and collaborative efforts to enable them to achieve results with internal and external transformation.

Our goal is to understand which government characteristics are important for those local governments endeavoring to develop smart urban governance. We assume that when endowed with certain characteristics, local governments will have the capacities required to implement smart urban governance. We seek to answer the following research question: what are the essential government characteristics of local government to achieve smart urban governance? For this, a systematic review of the literature available was conducted to design a framework that brings together those characteristics. The topic regarding the important characteristics and capabilities that organizations must acquire and use may appear somewhat examined in the literature, however, we took it a step further, bringing together a systematic literature review in smart urban governance with the literature on e-government and its organizational aspects, thereby, providing a rich understanding of the transformations required at an organizational level to achieve the expected results of smart urban governance.

Our work helps identify government characteristics that are essential to the development of smart urban governance. It may also help public managers to understand important characteristics and areas of improvement in government departments and agencies, allowing them to achieve smart cities. In this first section we introduce the chapter, we describe the governmental factors significant in adopting e-government in the second section, the methodological procedures used for data collection and analysis are presented in the third section, the smart urban governance concepts are detailed in the fourth section, while the fifth section presents our findings regarding the essential government characteristics for smart urban governance. The sixth section presents a discussion of our results and, finally, the seventh section concludes with our considerations and future research.

Government Characteristics for e-Government Adoption

Scholars from the e-government field understand the factors that characterize the adoption of IT in public organizations and have identified that internal organizational characteristics are crucial for implementing IT in public organizations (Liang et al., 2017). They have found aspects, such as professionalism, slack resource, administrative performance, the existence of a central IT department, and organizational perceptions of particular needs (for instance, the information workflow) (Liang et al., 2017) and, additionally, managerial support, organizational responsiveness, strategic plan placement, and technology champion (Savoldelli, Codagnone, & Misuraca, 2014). The studies also revealed that the government's capacity becomes more important when considering e-government performance. The literature indicates that the management of increasingly sophisticated programs requires skilled personnel and administrative resources (Pang, Lee, & DeLone, 2014) with five organizational capabilities mediating the relationship between IT resources and public value–public service delivery capability, public engagement capability, co-production capability, resource-building capability, and public-sector innovation capability. Researchers argue that IT resources in public organizations can enable public managers to advance public-value frontiers by cultivating these five organizational capabilities, and these IT resources and organizational capabilities can also overcome conflicts among competing values (Young, 2015).

Organizational factors encompass the governmental characteristics, e.g., size, type, and form, regional location, and metropolitan status, IT knowledge, skill, experience, and capacity, innovativeness, financial and IT human resources, need, and task, IT strategic plan, top management support, and its demographic and personal characteristics (Meijer, 2015). Institutional factors are regarded as critical to understanding the adoption process e.g., law, policy, and institution, budget norm and methodology, IT national strategy and standard, central government grants, intergovernmental relationships, political and bureaucratic structure, political support and guidance of a supervisor, within which a lack of institutional and political support is one of the main factors explaining the barrier to e-government adoption in recent years (Meijer, 2015). More recently, Liang (Stier, 2015) analyzed the factors influencing the adoption of modern technologies—such as the cloud suggesting that top management support, organization inertia, and the scale and complexity of information resources are crucial to this process. Meanwhile, the rational adoption decision is influenced by internal organizational readiness (top management support, organization inertia, information resource's scale and complexity) and external environmental stimulus (policies, standards, best practice, competition pressure, citizens' requirement, and financial fund). The support or barriers from organization readiness and environment stimulus will either accelerate or slow down the process between trust and adoption of the e-government cloud (Liang et al., 2017)

Additionally, researchers had paid attention to identifying structural barriers, such as organizational capacities, technological possibilities, and financial resources and cultural barriers (Al-Hujran, Al-Debei, Chatfield, & Migdadi, 2015). The most significant include a lack of technology or web staff and expertise, lack of financial resources, and issues around privacy and security (Liang et al., 2017). Müller and Skau (Norris & Moon, 2005) gave an overview of the e-government literature and established digitization success factors. Six categories of success factors were identified, including the external environment, organization, management, employees, citizens, and technology and their elements (Table 1).

According to these authors (Müller & Skau, 2015), organization characteristics include the rules, values, and norms of the organization, along with management, the employees, and their willingness to change. The reputation of the organization is also mentioned as this will impact the chances of implementation success. How the organization manages its resources also influences the possibility of a successful implementation of e-government. However, not all government agencies are identical, and the size and type of government agency also influence digitization efforts. Finally, benefits and costs to the organization are important factors to consider because of the impact on the implementation success of e-government initiatives.

Characteristics of management in the organization play an important role, for instance, the implementation readiness of management has consequences for the implementation of e-government services. Along with political consensus and political will in the organization, top management must support new projects to achieve successful implementation. It is, however, not enough to have top management support in general, commitment to specific projects is equally important. A barrier for e-government initiatives is a lack of internal ownership. When an e-government project does not have an owner with a clear division of responsibilities, the risk of failure increases as its focus might shift or even disappear (Müller & Skau, 2015).

Human resources are crucial in e-government implementation, especially in terms of the capabilities of their employees. Hence, a potential barrier is a lack of IT experts and employees interested in technology. The personal and political power relations also play an important role when implementing e-government, as they

Table 1 Success factors for e-government adoption

Category	General elements
External environment	Legislation Political and administrative reform Socioeconomic factors Culture
Organization	Characteristics Financial resources Infrastructure Collaboration Stakeholders
Management	Characteristics Commitment Strategy Managing the projects
Employees	Human resources Fear of change Training and education
Citizens	Digital divide Training and education Citizens' needs and trust
Technology	Infrastructure Design and access Security

Source: Adapted from Muller and Skau (2015)

influence employees' perceptions of new e-government services. Some employees are excited about new opportunities, but a potential obstacle is the lack of time to experiment, something considered essential for innovation and improving e-government services (Müller & Skau, 2015).

Technology infrastructure is important because insufficient infrastructure results in implementation failure. Conversely, a comprehensive infrastructure increases the likelihood of implementation success, as this makes it easier to develop existing services and developing underlying systems further. System integration makes the process of streamlining possible, which in turn increases the likelihood of e-government implementation success. Advancing e-government services is easier when existing systems are well-integrated, and the infrastructure is well-developed. It is also easier if the capabilities and capacities of existing systems are extensive, comprehensive, ubiquitous, transparent, and easy to use. The compatibility and integration of systems increase the likelihood of implementation success. Obstacles to data interchange and interoperability are implementation barriers, in addition to poor record management and inadequate data. When implementing e-government services, it is not only the inner workings of government that influences success, the ability of the IT industry to develop innovative systems to support government services is also very important. Those innovative IT systems must accommodate the complex needs of the public sector as well as individual citizens (Müller & Skau, 2015).

There are many different groups of citizens, therefore many considerations to take into account. The literature mentions the digital divide as a digitization barrier, reflecting demographic and social differences between citizen groups. When implementing e-government services, acceptance from citizens is key to its success, with many different factors influencing their acceptance. Some citizens are not e-government ready whereas others are (Müller & Skau, 2015).

Environmental factors include social, cultural, economic, and demographic, e.g., external coercive pressures and enforcement, stakeholder and citizen demand, best practices, and economic circumstances. Then, there are also demographics such as population size, citizens' education levels, incomes, race, and internet access levels (Stier, 2015).

The previous discussions in the e-government literature enumerate important organizational characteristics and external elements influencing the internal organizational environment when the public sector adopts IT. This corpus of literature offers an initial understanding of organizational characteristics that we should pay attention to when analyzing the smart governance literature. It also gives us the possibility to compare the two areas of literature, allowing the identification of existing differences and guide future research.

Methodological Procedures for the Literature Review

A systematic literature review was conducted to identify the key government characteristics for smart urban governance. The protocol for the review was developed based on PRISMA (http://www.prisma-statement.org/), and a set of rules was established for the literature search (Appendix).

The search was initiated by using the scientific databases of Scopus, PiCarta, Web of Science, and Social Science Citation Index, which include peer-reviewed articles, but only 11 relevant publications were identified, less than the search of Google Scholar. We realized that the algorithm of Google Scholar is not transparent but still opted to use Google Scholar because it yielded many more relevant publications. Since Google Scholar generated many articles looking for the above-mentioned search terms, the selection was made by reading all their titles, abstracts, and introductions to identify appropriate articles from the first page. Beyond the listed search criteria, the records were also assessed according to additional quality indications (journal, edited book by renowned scholars) and impact (number of citations). The detection process for each term continued onto approximate pages 10–12 when either irrelevant or already identified papers were easily identifiable. Guided by the above criteria, we identified a total of 96 articles for our literature analysis.

An Excel factsheet was created for encoding the articles, which were evaluated, analyzed, and interpreted by three researchers in three different countries. In the first step, the three researchers independently encoded the same ten articles, then results and methods were discussed, and the analytical factsheet was refined. For clarity, we formulated questions for each column in the spreadsheet so that the three teams had an identical understanding and perception of them. A more precise delineation was essential to ensure that the researchers interpreted the facets in question, which functioned similarly to strengthen inter-coder reliability. In the second stage, the remaining 86 articles were divided and coded by the same three teams independently, then the encodings were merged into a single Excel spreadsheet at the end of the process.

From this point forward, each team worked on the data from different perspectives. The teams analyzed and interpreted the results qualitatively since the perspectives of the topics, as presented in the papers, varied considerably in scope, nature, and depth. Two teams sought to map this variation and identify the various concepts and mechanisms. In this chapter, the third team focused on analyzing government characteristics, the variable with the highest volume of fragments of text extracted from the corpus of articles.

The conceptual model proposed by Miles and Huberman (Harrison & Donnelly, 2011) inspired our data analysis (see Fig. 1). The fragments of text extracted from the articles were organized, coded, and categorized into basic descriptive units, followed by an interpretative process that attributed meaning to the analysis. The fragments of text were systematized based on explicit and implicit meanings allowing the

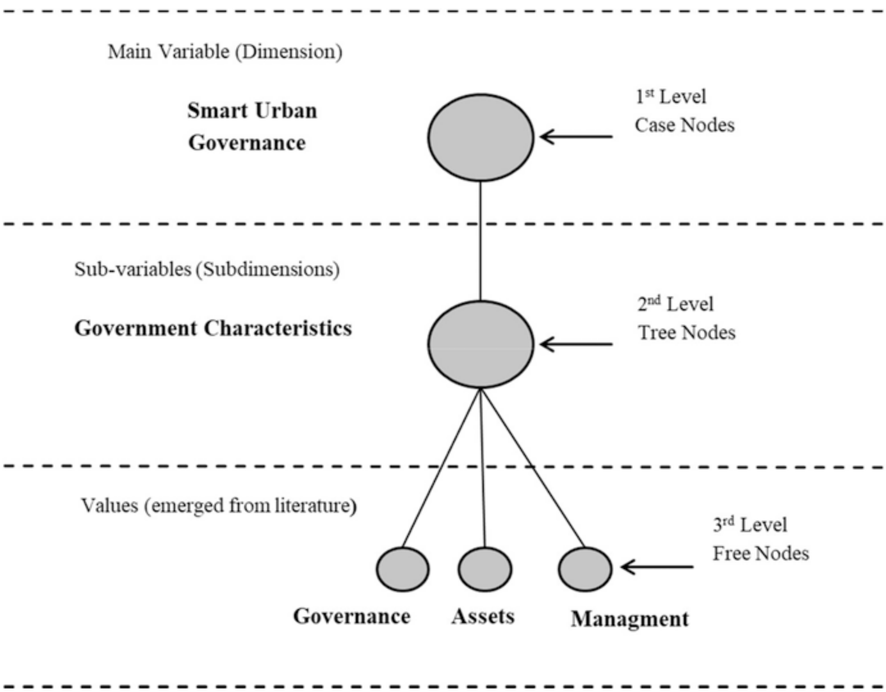

Fig. 1 Levels of the hierarchical dimensions (inspired by Miles & Huberman, 1994)

concepts and relevant government characteristics that emerged from the data to be identified. Qualitative analysis software was used to operationalize the analysis.

We began the analysis using open coding to explore the data by thoroughly examining what appeared to be relevant in the text fragments. Then axial coding was performed to identify the relationships between the initial categories that identified the nets. Finally, selective coding was used to identify the central categories to which all the others are related.

The first round of open and axial coding was performed by a researcher, with the results presented for critique by all the members of the research project during a meeting. At this meeting, some possibilities for central categories emerged. The second round of analysis was performed to refine the coding, resulting in three central categories, 13 subcategories, and 40 elements. The entire process of data collection, analysis and, interpretation lasted 12 months.

In our analysis framework, the first level originates from the literature and represents the concept of smart urban governance. The second level represents the government characteristics variable, which we set out to understand in-depth. The third level emerged from the analysis of the literature review, representing the core categories of the identified government characteristics: governance, assets, and management, as detailed in the following section.

Smart Urban Governance

Smart urban governance is about creating new forms of collaboration among citizens and governments, using ICTs to obtain better results and provide more open urban governance processes (Meijer & Bolivar, 2016). Smart urban governance represents a set of technologies, people, policies, practices, resources, social norms, and information that all serve to support urban governmental activities. Governance is at the core of interactions and defining the directions of smart city practices represents a major challenge. Public organizations use ICT to facilitate communication and transactions with many stakeholders, both in the public and the private sectors. Similarly, the adoption of ICT in government and society has made significant impacts on the organizational effectiveness, efficiency, and innovativeness of public organizations (DG.O. Call for Papers dg.o, 2017). Considering the views of different academic fields—e-government, public administration, and urban governance studies—it is possible to understand and develop a perspective on smart urban governance, which begins with the notion of strategic alignment between the use of ICTs and the urban governance strategy (Henderson & Venkatraman, 1993).

Smart urban governance is also about making the right policy choices and implementing these effectively and efficiently. Smart governance emphasizes the need for smart decision-making processes and the implementation of these decisions. New technologies are used to strengthen the rationality of governments by using more complete—and more readily available and accessible—information, helping in governmental decision-making processes and subsequent decisions (Meijer & Bolivar, 2016). Smart urban governance includes creating a smart administration. A new form of electronic governance can emerge, using sophisticated information technologies to interconnect and integrate information, processes, institutions, and physical infrastructure to better serve citizens and communities. This type of smart governance is at a higher level of transformation since it requires the restructuring of the internal organization of government, as a result, administrations will need to be innovative to deal with the requirements of differentiated policies (Meijer & Bolivar, 2016).

The most transformative level of conceptualization stresses that smart governance is about the smart urban collaboration between the various actors in the local government. Meijer and Bolivar (2016) qualify this conceptualization as the highest level of transformation since it is not only about the transformation of the internal organization but also the external environment. Smart governance is the widespread adoption of a more community-based model of governance with greater connectivity facilitated by new technologies. It is the proactive and open-minded governance structures, involving all actors. It is important to maximize the socioeconomic and ecological performance of cities while coping with both negative externalities and historically grown path dependencies (Meijer & Bolivar, 2016).

In this chapter, we have considered the last conceptualization of smart urban governance, ICT-enabled citizen-government collaboration. The concept entails aligning technological potential with sustainability strategies and collaborative innovations, important for forming a consistent socio-technical approach to addressing urban problems (Capra, 2016; Meijer & Bolivar, 2016; Meijer & Thaens, 2016; Paskaleva, 2014; Ramon Gil-Garcia, Helbig, & Ojo, 2014). Just as the local government plays an important role in smart urban governance by focusing on organizational and managerial strategies, managerial innovativeness is the most compelling reason for local governments adopting new ICTs in their core functions. Managerial innovation affects the degree of technological innovation and administrative innovation (Bakıcı, Almirall, & Wareham, 2013), therefore, this chapter focuses on the analysis of government characteristics to gain a deeper understanding of the essential issues for smart urban governance, and how to describe these elements according to literature.

The Essential Government Characteristics for Smart Urban Governance

According to our literature review analysis, the most important government characteristics required for local governments to encourage smart urban governance are governance, assets, and management. Smart urban governance requires the collaboration of several partners, which can be activated using online and/or offline mechanisms. Additionally, there are essential assets such as funding, technology, and human capital. Finally, local governments must rely on elements of management and project implementation strategies suitable to the legal and policy context, vision and leadership, principles, project design, communication, strategy, and organization cultural aspects (see Fig. 2).

In the following subsections provide details of each government characteristic and its elements, supported by selected quotations from the articles.

Governance

Governance is related to the nature of the relationship between the state, market, and civil society (individuals and interest groups). These imply networking, collaborative environments and integrated outcomes (Ramon Gil-Garcia et al., 2014). In our analysis, defining governance is an important characteristic of public administration. We identified three elements that are essential to smart urban governance: conformation, involving partnership actors, and mechanisms.

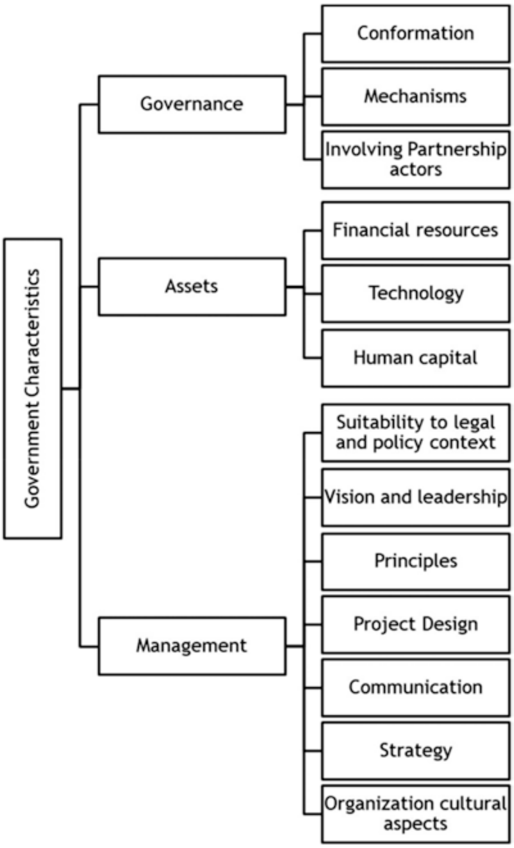

Fig. 2 Government characteristics framework that emerged from the literature review

Conformation is associated with the how governance is activated by the government: promoting participation, open to collaboration, or stimulating co-creation. One way is participative when a government formally invites agents to participate, which is positively associated with sustainability (Abu-Shanab & Al-Quraan, 2015), and the engagement of citizens in decision-making could help accomplish government policies and the delivery of services. Collaboration is related to citizens becoming involved midway through the planning process, as cooperation between the various players involved leads to knowledge transfer and the empowerment of those involved. In co-creation, the actors are considered key players in the process of defining the type of applications to be used, playing the role of both content developers and consumers (Abu-Shanab & Al-Quraan, 2015).

The relationships between the various actors influence governance (Ramon Gil-Garcia et al., 2014). "Involving partnership actors" highlights that a set of partnership actors must be considered, such as business, government, and civil society. All these actors can play different roles and have their reasons for participating in smart urban governance. However, this rich diversity of actors provides different perceptions of problems, and various strategies are developed when searching for solutions.

Finally, there are mechanisms for implementing governance and involving actors. We have identified a set of online tools, such as crowdsourcing, social media, and apps, and offline tools, such as face-to-face events and public audiences. There is also a hybrid form, an example being living labs, which combine online and offline tools to bring in more partners and engage citizens. Table 2 presents all these elements of governance, the number of quotations identified in the categories, and an example of text exert to illustrate how the quotations support our analysis.

Assets

This set of government characteristics involves useful or valuable elements that support smart urban governance, such as funding, technology, and human capital. According to our literature analysis, some smart urban governance initiatives depend on financial resources (Castelnovo et al., 2015; Cleland et al., 2012; Yetano & Royo, 2015), and sometimes the lack of funding is a barrier to implementation.

Technology is another important asset identified in the literature, as we consider the involvement of actors supported by technology. The technological tools developed for smart urban governance must be user-friendly (Bolgov et al., 2014), understandable (Sirajul Islam, 2008), and easy for citizens to use (Kingston, 2007). Another important aspect of technology is the architecture and general technical requirements, such as privacy, security, language, and hardware. The digital tools should be available on a platform and should preferably use open technology (see Table 3). Also, the design process of these tools must take citizen participation into account in their development, validation, and implementation. In fact, co-design could result in greater engagement and tools that are more suitable for local structures and contexts (Lang & Roessl, 2011).

Table 2 Governance

			n°	Selected quotation
Governance	Conformation	Promote participation	18	One of the features that helps distinguish cities' sustainability efforts is the extent to which such efforts seek to promote citizen participation and involvement (Stratigea, Papadopoulou, & Panagiotopoulou, 2015)
		Open to collaboration	9	The focus on the creation of collaborative models allows the experimentation of innovative partnerships, including some with informal settings (Paskaleva, 2014)
		Stimulate co-creation	11	Co-creation is a key asset to the formulation of answers to complex challenges and the improvement of new public value generation processes in non-linear and unpredictable environments (Royo, Yetano, & Acerete, 2014a)
	Involving partnership actors	Market	3	Companies could provide the means for innovation and exploit their results. There is also the possibility of new start-ups from innovative products developed by citizens (Santos et al., 2015)
		State	4	Government actors: act as a partner and not as a decision-maker (Paskaleva, 2014)
		Civil society	23	Middle ground organizations play a fundamental role in engaging with communities, especially in technologically complex projects (Paskaleva, 2014) Involve users: it is crucial that a wide range of stakeholders are involved during development (Lang & Roessl, 2011) The authorities, with the support of highly trained volunteers, mainly focus on mitigation measures, dealing with emergencies, optimizing resources and providing effective and rapid support as and when needed (Wayi & Huisman, 2010)
	Mechanisms	Online tools	13	Citizens mentioned the possibility of the online evaluation of public servants and the possibility of acting in the socio-political sphere (including e-petitioning and e-discussions) (Wehn, McCarthy, Lanfranchi, & Tapsell, 2015)
		Offline tools	1	There is a relationship between attendance at face-to-face events and continuity of participation, confirming previous findings that offline relations have beneficial effects on online interactions (Bolgov, Chugunov, & Filatova, 2014)
		Combine online and offline tools	3	Living labs is a partnership of differing and sometimes competing interests, and they are often regional actors with regional remit and outlook, with all that entails (Yetano & Royo, 2015)

The final asset identified in our analysis was human capital, the availability of human resources with capabilities and skills in management and technology within the local public administration. These are important characteristics of smart urban governance, and these skills must be present in the community (see Table 3).

Management

Management is related to elements of strategy and the positioning of local public administration: communication, project design, principles, vision and leadership, and suitability to legal and policy contexts. Without leadership and a formalized strategy, cities may not be able to operate smart developments effectively (Meijer, 2015). Suitability to legal and political contexts can have an important impact on the implementation of smart urban governance. The legislation is essential to guaranteeing achievements such as individual privacy (Bolgov et al., 2014) and facilitating participation, so a legislative framework may be required to accomplish a level of integration that makes participatory practice in smart urban governance possible. In some cases, in addition to a legal framework, internal norms and rules must be established. Local government plays a role in leadership and vision in terms of moving from strategy to implementation. It must implement a governance model with strong external ties, allowing citizens to participate. An analysis of the literature available reveals that a clear vision and strong leadership by the mayor/elected official and the city council are differentials that have proven to be pivotal for innovative local e-governance (Ramon Gil-Garcia et al., 2014). Nevertheless, the involvement of other actors, citizens, decision-makers, public administrators/planners, and representatives of other spheres of government increases the chances of smart urban governance outlasting the mandate of a governor.

Governance models can be designed through different strategies, and design projects for smart urban governance may also follow a top-down approach. There are advantages to this approach, such as maintaining focus, but there are also disadvantages, such as establishing boundaries (Torres et al., 2006). The participative approach allows other actors to participate in decision-making (Abu-Shanab & Al-Quraan, 2015), while the collaborative approach entails a greater commitment (Lee, Hancock, & Mei-Chih, 2014). In the literature review, “Participative” and “Top-down” approaches were suggested as possibilities to design projects despite the fact they seem contradictory. It does not mean that a local government should choose which of them to consider - rather, the projects studied by other authors have considered these two approaches. Notice that the bottom-up perspective was not identified in the literature, although this could occur in some cases.

Communication is another important element and exists in a variety of forms, such as broadcasting information, feedback when the government responds to citizen participation, and new forms of communication, such as apps and social media (see Table 4). It should be pointed out that communication must be interactive and multi-party, involving local government and other players.

Table 3 Assets

			n°	Selected quotation
Assets	Financial resources		20	Administrators may lack the time and financial resources necessary for meaningful citizen involvement to occur (Prieto-Martín, de Marcos, & Martínez, 2012)
	Technology	Understandable and friendly tools	18	One of the key factors to the success of delivering services is a clear, well presented, understandable interactive tool (Sirajul Islam, 2008). The design includes a series of meetings between the user and the developer to identify various system features and needs and convert them into a design for a system (Lang & Roessl, 2011)
		Security and privacy	8	Security and privacy issues; upgrade technology (Sirajul Islam, 2008); Computer language, hardware platforms, tools (Lang & Roessl, 2011)
		Internet reach and use	14	Technology is behaving as an enabler within pre-existing social and political structures (Royo, Yetano, & Acerete, 2014b)
		Urban ICT infrastructure	11	City infrastructures including ICT infrastructures and systems, are enabling factors for the development of smart cities and need to be governed (Castelnovo et al., 2015)
		Use open technology	7	The philosophy behind open source and the co-creation of open source systems could be fundamental keys for the movement toward a sustainable society (Santos et al., 2015)
		Developing a platform	4	Electronic networks and platforms should be used to either direct the participants to the discussions or as a tool for participation, although it must be considered carefully as not all participants may have access to the technology or the tolls (Torres, Pina, & Acerete, 2006)
	Human capital	Government staff competences	7	As part of management quality, public officials' interpersonal, discourse and facilitation skills have been emphasized as a means of implementing authentic participation programs, which require citizens' active participation (Edelmann, Hoechtl, & Parycek, 2009)
		Availability of staff'	3	Factors that affect government organizations' […] human resource endowment (Cleland et al., 2012)
		ICT skills	10	Planners may be unfamiliar with how new technologies can be used effectively (Lee & Kim, 2014)
		Promote expertise in the community	11	One of the main challenges of participation addresses the status given to citizen knowledge in policy-making (Lee & Kim, 2014)

Table 4 Management

			n°	Selected quotation
	Suitability to legal and policy contexts	Regulation/ legislation	15	There are several legal requirements for citizen participation in different areas of urban planning (Edelmann, Hoechtl, & Sachs, 2012)
		Norms/rules	6	The governance norms and practices of the various institutional sectors tend to shape key actor participation, in turn, influence the process and outcomes of ICT and internet diffusion (Kubicek, 2007)
	Vision and leadership	Citizen-centric	1	If citizens feel that their contribution to open government projects is meaningful, they will be more motivated to engage in such projects (Azad et al., 2010)
		Government and political leadership	9	In the more advanced cities, the roles of the mayors and the city council have proven pivotal for innovative local e-governance, despite acknowledging the importance of networking and collaboration (Ramon Gil-Garcia et al., 2014). Political actors should promote and support participation in the form of open government projects (Azad et al., 2010). The involvement of the government is essential: it provides trust, open data, long-term commitment, policy, and leadership (Paskaleva, 2014)
		Public managers support	5	The serious involvement of decision-makers throughout the participation process is a critical (and often missing) success factor (Kingston, 2007). The role of planners is of crucial importance: agents to change initiators and managers of the whole participatory experiment (Abu-Shanab & Al-Quraan, 2015)

(continued)

Management	Principles	Flexibility	1	Be flexible: the chosen methodology should be flexible in many respects (Lang & Roessl, 2011)
		Interactivity	3	Potential drivers behind governmental promotion for e-participation in environmental issues: the interactivity of government environmental websites (Stratigea et al., 2015)
		Simplicity	1	Be simple: people from rural areas are illiterate and have a limited understanding of information systems (Lang & Roessl, 2011)
		Sustainability	4	Without smart and sustainable design principles encoded into law, communities wishing to become smart or get smarter (with or without e-learning and digital information platforms) stand little chance of achieving their vision in the chaotic and competitive milieu of social, technical, and economic change (Wijnhoven, Ehrenhard, & Kuhn, 2015)
		Transparency	6	Information processes should be transparent and comprehensible for citizens (Azad et al., 2010)
	Project design	Collaborative	15	Creating stability in the relationship and providing a stronger basis for cooperation is a must for citizen satisfaction, trust, and future participation willingness (Prieto-Martín et al., 2012)
		Participative	7	Participatory planning: allows stakeholders and citizens to take part in the decision-making process and share control over development initiatives and the decisions and resources that affect them (Abu-Shanab & Al-Quraan, 2015)
		Top-down	5	At present, most e-government initiatives are still viewing people from a passive perspective—to whom something is given or from whom something is required—and not as citizens (Royo et al., 2014b)
	Communication	Broadcast	2	Publicizing all aspects and inclusions of e-participation should be given more emphasis by the supply side (Cleland et al., 2012)
		Feedback	6	Feedback mechanisms need to be implemented too. It often remains unclear how citizens can follow-up on their contribution, particularly given the timespan of policy-making (Lee & Kim, 2014)
		Responsiveness	4	Quality responsiveness from the government motivates e-participants to stay longer and to participate in the online community frequently. Sincere responses from e-participation management reinforce e-participants' interest in e-participation and their willingness to engage in e-participation by facilitating their commitment (Edelmann et al., 2009)
		New forms of communication	10	Future apps need to be developed with an understanding of how to communicate during and in the aftermath of the participatory process (Edelmann et al., 2009). Communication can take place on a multiplicity of channels on and offline, public, and private (Kingston, 2007)
	Strategy	Organizational structure	24	Public administrations and governments need to rethink their operational structure as well as their interaction with citizens (Martínez-Ballesté et al., 2013)
		Coordination	16	Coordinated leadership is required for making e-participation or self-managed digital grassroots organizations more effective (Cleland et al., 2012)
		Strategic process	25	Smart city strategy: formal, comprehensive smart city strategy reviewed and revised regularly to be aligned with the city's specific strategic initiatives (Meijer, 2015)
	Organization cultural aspects		8	The importance of organizational cultural barriers: […] organizational values may work against the development of electronic services (Ertiö, 2015)

Another element of organizational management is the principles that guide the development of smart urban governance. Principles - based on flexibility, interactivity, simplicity, sustainability, and transparency can lead to positive results concerning participation and work as enablers of smart governance. These principles are potential drivers for government promotion of citizens' participation and collaboration.

Finally, other strategic elements of government characteristics should be considered as part of the organizational structure. Some authors mention the need for significant changes to the traditional structure (Cleland et al., 2012; Martínez-Ballesté, Pérez-Martínez, & Solanas, 2013). Good coordination and strategic processes are also important, including planning and establishing goals and programs, content development, processes and tools, promotion and post-implementation (Cleland et al., 2012).

An environment and organizational culture are needed in which political representatives are committed and willing to engage in participation. Aspects of organizational culture can affect the adoption and implementation of smart urban governance, such as resistance to changing existing routines and values.

From e-Government to Smart Urban Governance

When comparing the literature in e-government with the literature in smart urban governance, the government characteristics considered important seem to be similar, with elements—such as project management, financial resources, human capital, technology, vision, and strategy—appearing in both corpora of literature. Differences emerge when the focus of these elements is analyzed (Table 5). When discussing government characteristics in e-government, these characteristics focus on the internal environment of public administration and government agencies. Janowski (Müller & Skau, 2015) presents e-government as a transformation of internal government, but not the transformation of external relationships (Meijer & Bolivar, 2016). In smart urban governance literature, there is still a concern about the internal environment of public agencies (Meijer & Bolivar, 2016). However, the focus here is on creating conditions to expand collaboration with the external environment, what Janowski (Müller & Skau, 2015) presents as the transformation of internal government and the transformation of external relationships. Meijer and Bolivar (2016) also characterize levels of transformation of government structures from smart urban governance, arguing that this can start with better public administration, a move to innovation in decision-making processes, achieving innovation at organizational and management level, then reaching governance networks. Our review of the literature on smart urban governance reinforces the arguments that government agencies need to prepare to create internal and external innovation in partnership with different actors, to provide solutions for urban challenges (Table 5).

Table 5 Comparing the government characteristics

e-Government (Müller & Skau, 2015)		Smart urban governance	
Dimension focus		Dimension focus	
External environment	• The factors of the external environment, for example, legislation, political commitment, socioeconomic aspects, and culture are considered important, however, they are seen as externalities	Governance	• There is no strong separation between the internal and external environment. The government needs to be prepared to work with more horizontal and widespread governance • Collaboration takes place between government levels, government and stakeholders, and tries to accommodate different interests. The stakeholders are included from the outset in a co-production process • Government organizations should be endowed with governance capacities, promoting participation, open to collaboration and stimulating co-creation to create opportunities for interaction within stakeholders through online and/or offline tools • Citizens play a central role in achieving the smart urban governance outcomes (i.e. sustainability) and they co-produce the solutions for cities
Organization	• The organization is seen as a set of rules, values, and norms along with management, the employees and their willingness to change • An organization needs to be endowed with financial resources for implementing e-government, and infrastructure that includes the organizing principles which influence organizational behavior • Collaboration is restricted to government agencies and employees when implementing e-government services or to provide information to each other. Stakeholders are important to ensure better implementation of services		
Citizens	• The government must face the digital divide to allow digitization and provide education and training for citizens. This helps decrease the digital divide increasing the likelihood of successfully implementing e-government • Citizens are viewed as users		

e-Government (Müller & Skau, 2015)		Smart urban governance	
Dimension focus		Dimension focus	
Management	• The government must have the readiness to manage the implementation of e-government services • Top management must support new projects to achieve implementation success • It is important to align e-government projects with online strategies that focus on how to deal with internal and external challenges • Management aspects should be considered, including relationships, risks, plans, and supply management to ensure that projects are implemented correctly and on time	Management	• A new legal framework may be required to accomplish a level of integration that makes participatory practice in smart urban governance possible • Local government must implement a governance model with strong external ties, allowing external actors to participate • Some principals can lead to positive results concerning participation and work as enablers of smart urban governance • Projects could be implemented following different strategies, more top-down or more participative • Communication among government and citizens is crucial for developing trust • The strategy includes moving from a traditional structure to open collaboration, but still under good coordination
Employees	• The capabilities of the employees are crucial, especially IT skills. However, employees are skeptical, and fear of redundancy is an implementation barrier that negatively affects the cooperation of employees. Employees must be trained and educated in using the new services to ensure the best citizen service possible	Assets	• Availability of human resources with capabilities, and skills in management and technology within local public administration, as well as in the community • Availability of ICT infrastructure and good design of the tools • Financial resources are necessary to implement projects
Technology	• ICT infrastructure increases the likelihood of implementation success because it makes it easier to further develop existing services and underlying systems. Good website design, focused on user-friendliness, is essential. Security and privacy are crucial		

Final Considerations

This study was guided by the following research question: what are the essential government characteristics of local government to achieve smart urban governance? Based on a systematic review of the literature available, we identified the main characteristics and essential elements: governance, assets, and management. Local governments play an important role in smart urban governance. By understanding the government characteristics of smart urban governance through the available literature, we have been able to study it more empirically identifying some essential government characteristics for smart urban governance. According to the literature, smart urban governance is the most transformative level of governance and concerns smart urban collaboration between the various actors in local government (Meijer & Bolivar, 2016). This high level of transformation is not only about the internal organization but also about an external organization (Janowski, 2015). Therefore, the government characteristics of local government required an innovative approach, focusing not just on internal capabilities, like in e-government. The public administrations should stimulate the collaboration and co-creation of these by new technologies. The study contributes to this theory by proposing a framework of government characteristics that are important for smart urban governance, while also drawing out some guidelines for future research:

Situational context: to identify the specific government characteristics dependent on the local context. Specific mechanisms and conditions will help local governments to develop forms of smart urban governance that work in their specific (national and policy) context, for instance, the forms of urban governance and political system.

Necessary assets: how to create conditions to raise assets (financial, technological, and human resources) to prepare organizations for smart urban governance; how the availability of urban ICT infrastructure is a determinant to reach smart governance; and how to deal with the digital divide.

External actors' engagement: how local governments could better engage citizens and other stakeholders for smart urban governance. Almost all literature affirms that involving stakeholders is essential for achieving smart urban governance, but it is still not clear how to do it. It is also unclear what role external actors should assume or how to create organization capabilities to deal with possible tension between different interests.

Internal government capabilities: how can government organizations prepare to generate internal, as well as extend to external transformation? In part, this literature review points to the characteristics of management needed to achieve smart urban governance, yet, it is still necessary to identify the management tools that have allowed for greater collaboration. The outcome of this future research might provide a better understanding of how to implement smart urban governance in different settings—settings that require different government characteristics.

This study offers a practical contribution by providing insights for public administrators as they prepare/implement their projects.

Acknowledgments We extend our thanks to the Utrecht University and Stirling University teams for their collaboration and to São Paulo Research Foundation (FAPESP) for funding the research project, grant 2015/22960-1; grant 2017/09343-2.

Appendix

(a) Topics and disciplines: The aim was to collect diverse perspectives concerning smart urban governance. Due to the interdisciplinary nature of our research, perspectives from a broad variety of study fields were included, such as public administration, policy studies, e-government studies, spatial sciences, urban planning, sustainability sciences, urban/sustainability governance, innovation science, and urban and community informatics.

(b) Study and research design: all types of research design were included in the review (case studies, questionnaires, experiments, literature reviews, comparative research, etc.).

(c) Period of publication: The retrieved studies were published from 2006–2016. The planning and use of ICT for participatory/collaborative governance to address urban problems is a somewhat new phenomenon, which began to unfold particularly over the last decade. Additionally, the association of smart cities with ubiquitous urban computing began after 2005 (Chourabi et al., 2012).

(d) Language: only journals, reports, and analyses, etc. written in English were considered. The literature review is embedded within an international project across three countries, therefore, the selection of the English language as the standard in our correspondence was the most practical and reasonable option. Moreover, significant articles of trustworthy scientific quality written outside the Anglo-American academic community are presumably written in or translated into English as well.

(e) Publication status: To retrieve a greater number of related articles and diverse outlets, we included international peer-reviewed papers as well as proceeding papers, books, book chapters, and doctoral theses. This wider range of alternatives is useful for using high-quality scientific publications to generate a theoretical design and helpful for identifying cutting-edge work in this field, often created by practitioners, which aligns with our main target group: policy-makers.

(f) Keywords/search terms: Due to the multidimensionality of the research field, it is challenging to formulate search terms or their combinations to cover the dimensions denoted in the review questions. We searched a combination of terms to select the most appropriate papers as the use of single terms results in an enormous number of papers. We began with the following combination: citizen e-participation urban sustainability, smart city participation sustainability, city participation ICT sustainability, governance e-collaboration citizen sustainability, smart city citizen sustainability, e-participation co-creation sustainability, and collaborative e-governance.

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Part II
Policy

Review of International Standards and Policy Guidelines for Smart Sustainable Cities

Elsa Estevez, Karina Cenci, Pablo Fillottrani, and Tomasz Janowski

Abstract Smart cities are often criticized for preoccupation with technology, for ignoring the negative effects of technology, for irrelevance to the needs of the poor, and for ubiquitous data collection creating perfect conditions for surveillance societies and autocratic states. In response, cities pursue smartness and sustainability simultaneously, becoming global (by participation in global digital networks) and local (by addressing local needs and circumstances) at the same time. In the pursuit of smart sustainable cities, they make explicit policy decisions about how technology should serve their residents, businesses and visitors, and avoid disrupting them. Many decisions are about standards—which standards should be followed and how, and increasingly, standards and policy guidelines are adopted by cities from international organizations, circumventing national authorities. This chapter reviews international standards and policy guidelines published by international standards organizations or intergovernmental bodies, with stated goals to support member

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_4

states in the development and management of smart sustainable cities. We conducted the review through exploratory research and comparative policy analysis. The result could be used to raise awareness and address knowledge needs among city managers, policy analysts, and smart city researchers.

Keywords Smart cities · Smart sustainable cities · International standards · International policy guidelines

Introduction

As a concept, policy, and practice, smart cities are criticized for their preoccupation with technologies at the expense of citizens, for ignoring the negative effects of the technologies upon which they are based, for irrelevance to the needs of the poor living in low-income countries, for making a naturally haphazard urban development process rigid and inhuman, for ubiquitous data collection creating perfect conditions to building surveillance societies and autocratic states, etc.

In response, we increasingly expect cities to pursue smartness and sustainability simultaneously (Estevez, Vasco Lopes, & Janowski, 2016). The former makes cities global "because they spread all over the world and emerge with similar features and interdependencies at the global level" (Paola, Benevolo, Veglianti, & Li, 2019). The latter makes them local "because each city is unique, has different problems, and should address them with specific solutions" (Paola et al., 2019). Smart sustainable cities are, therefore a prime example of the glocalization trend, "the simultaneous occurrence of both universalizing and particularizing tendencies in contemporary social, political, and economic systems" (Encyclopedia Britannica, 2020).

Treated as large socio-technical systems, what makes smart cities sustainable is that they put technology at the service of the local community. They deliver productivity, accessibility, wellbeing, livability, governance, and other outcomes expected by the local community (Yigitcanlar et al., 2018). These expectations expressed through political processes and political activism aim at influencing public policy. Thus the main types of drivers for smart sustainable cities are a community—users of city infrastructure, recipients of city services and deciders of city policies; technology—digital means to increase the quality of life for residents and visitors alike; and policy—enabling digital transformation and managing its negative effects (Yigitcanlar et al., 2018). Consistent with that, the analysis of drivers from the perspectives of applied social sciences, engineering, exact and Earth sciences, and human sciences reveals eight extremely important drivers (Azevedo Guedes, Carvalho Alvarenga, Goulart, Rodriguez y Rodriguez, & Soares, 2018): urban planning, city infrastructure, mobility, public safety, health, sustainability, public policies, and urban risks.

The responsibility for the formulation and implementation of public policies for smart sustainable cities rests with municipal governments. As the city undergoes digital transformation, so does its government. Transformation from government to digital government requires policy interventions (Chauhan et al., 2008) in order for digital government to enable public service innovation (Bertot et al., 2016) and contribute to sustainability goals (Estevez et al., 2013; Estevez & Janowski, 2013). On the practical level, to facilitate implementation, ensure safety and compatibility, lower costs, and build upon best practices, policies for smart sustainable cities often work through standards. Standards define "what people must do to be compliant and define the bar against which that compliance will be measured" (Capgemini, 2012). In contrast, policies generally make decisions on what standards we should follow, whether we should implement them, and how the implementation should proceed (Capgemini, 2012).

We enact many smart city standards on the national level. For instance, the British Standards Institution produced a particularly useful framework (British Standards Institute, 2015). The framework divides standards into strategic—guidance on developing priorities, roadmaps, and strategies; process—procuring and managing smart city projects; and technical—technical specifications that are needed to implement smart city products and services. The US National Institute of Standards, Smart Cities Council for Australia and New Zealand, and countries in the Asia-Pacific region all undertook similar standardization initiatives (Worldsensing, 2019).

However, most city governments, national government, and even intergovernmental bodies are trying to implement standards published by the International Organization for Standardization (ISO), International Telecommunication Union (ITU), International Electrotechnical Commission (IEC), European Telecommunications Standards Institute (ETSI), and other international standards organizations, and become "certified" through them (Worldsensing, 2019). For example, the European Union adopts various standards for smart cities, such as the standards on infrastructure performance (ISO/TS 37151:2015: 2015), open data (UNE 178301:2015: 2015), resilience and smartness (ISO/DIS 37101), city services and quality of life (ISO 37120:2014: 2014), universal accessibility (PNE 178106), accessible mobility (PNE 178306), smart tourism destinations (PNE 178501), and others.

Among them, an important category of standards is those defining indicators for measuring aspects of smart sustainable cities and tracking progress in building and maintaining them over time. City managers use such indicators for "target setting, performance assessment, monitoring, management, and decision-making purposes" (Huovila, Bosch, & Airaksinen, 2019). They are also key to managing policy implementation, monitoring the success of such implementations, and facilitating learning. Indicator-driven policy implementation is particularly important considering the multidimensionality of smart sustainable cities, the difficulty of maintaining policy coherence in the presence of multiple policy instruments, and stakeholder participation.

The analysis of seven recently published indicator standards (Huovila et al., 2019) uncovered a division between standards for measuring smartness and standards for measuring sustainability, standards oriented on measuring impact versus those oriented on measuring progress toward implementation according to different implementation steps, and different types of indicators—input, process, output, outcome, and impact.

In addition to standards published by various national and international bodies, policy recommendations and other policy initiatives are also offered by international bodies to their member states to facilitate the development and management of smart sustainable cities. Offering limited contextualization, they help bridge a design-reality gap between universal policies and standards and local goals and circumstances where we implement such policies and standards. Examples are the recommendations issued by the BRICS Smart Cities Movement (Global Policy Journal and Observer Research Foundation, 2017) or rules and recommendations issued by UNESCWA as part of the Government Summit on Smart Cities in the Arab Region (The Government Summit, 2015).

This chapter aims at reviewing international standards and policy guidelines, particularly those published by international standards organizations or intergovernmental bodies, with stated goals to support member states in the development and management of smart sustainable cities. Such standards and policy guidelines are a reflection of the glocalization trend—"increasing transnational interactions among subnational entities from different countries" and "contacts among subnational and supranational entities" circumventing the national executives' "gatekeeper position between the international and the domestic political spheres" (Encyclopedia Britannica, 2020). We conduct the review through exploratory research and comparative policy analysis. The expected outcome and contribution is a systematized inventory of relevant standards and policy guidelines allowing for analysis and comparisons, addressing the knowledge needs and raising awareness among city managers, policy analysts, and researchers.

We divide the chapter into six sections. Section "Research Methodology" presents the research questions and methodology adopted to address them, followed by the review of relevant literature to establish background knowledge in Section "Related Work", followed by the review of ten international standards and policy guidelines in Section "Policy Documents". Section "Analysis and Discussion" presents the analysis and comparison of such documents. The final Section "Conclusions" summarizes the main findings, outlines the limitations of this research, and draws some directions for possible future work.

Research Methodology

This chapter conducts a review, analysis, and comparison of international standards and policy guidelines for smart sustainable cities. We conduct the review by exploratory research of relevant documents published by international standards organizations and relevant intergovernmental bodies. Two questions guide this research. First, what international standards and policy guidelines exist to help develop and manage smart sustainable cities? What do they include, and where are they applied? Second, how can we compare such documents and the prescriptions contained therein? The work extends exploratory research into the nature and practice of smart sustainable cities documented in (Estevez et al., 2016).

The research relies on the secondary data obtained through research and policy literature reviews. The review of research literature aimed at uncovering scientific publications on smart city policies and standards and other related work, and establish the contribution of this work. We document the results related to background concepts in the Introduction section and related work in Section "Related Work". The review of policy literature reports on the results of two kinds of Internet searches. The first explores the websites of international standards organizations and other intergovernmental organizations working in the domain of standards, smart cities, and international policies. In particular, we explored the websites of the International Organization for Standardization (ISO),[1] the International Telecommunications Union (ITU)[2], and the European Commission (EC).[3] The second search looks for relevant policy guidelines targeted at the regions like Western Asia through the United Nations Economic Commission for Western Asia (UNESCWA),[4] the BRICS[5] country group, and others. From the identified documents, those considered most relevant by the authors were selected and synthesized. We present the outcome in Section "Policy Documents". The content of this section provides an answer to the first research question. The standards and policy documents presented in Section "Policy Documents" are analyzed, compared, and presented in Section "Analysis and Discussion". The content of this section provides an answer to the second research question.

Related Work

Related work includes: "Smart Sustainable Cities—Reconnaissance Study" prepared under the auspices of the International Development Research Centre (Estevez et al., 2016); "Pre-Standardization Study Report—Technical Requirements Analysis of Unified, Secure & Resilient ICT Framework for Smart Infrastructure" published by the Bureau of Indian Standards (Bureau of Indian Standards, 2017); and "Standardization for the sustainable development of cities and municipalities" coordinated by the Austrian Federal Environment Agency (Smart City Standards Normung für die nachhaltige Entwicklung von Städten und Kommunen, 2015). For each of them, we discuss their main contributions and a comparison with the results presented here.

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[1] ISO, https://www.iso.org/home.html, last visited 2020-02-01.

[2] ITU, https://www.itu.int/en/Pages/default.aspx, last visited 2020-02-01.

[3] EC, https://ec.europa.eu/, last visited 2020-02-01.

[4] UNESCWA, https://www.unescwa.org/, last visited 2020-02-01.

[5] BRICS Countries—Brazil, Russia, India, China and South Africa, http://infobrics.org/, last visited 2020-02-01.

The first study (Estevez et al., 2016) aims at assessing the state of the art and state of practice in smart sustainable cities. Based on secondary data, it conducted exploratory research of scientific publications, policy documents, and 21 case studies of smart sustainable cities. The current study is broader than the one in (Estevez et al., 2016). Regarding the analysis of policy documents, (Estevez et al., 2016) discusses the ISO 37120:2014 standard "Sustainable development of communities—Indicators for city services and quality of life" and the ITU standard on "Key Performance Indicators in Smart Sustainable Cities". In contrast, this chapter presents several major standards and policy recommendations issued by international organizations including those two standards.

In the second study (Bureau of Indian Standards, 2017), the Bureau of Indian Standards aims at identifying "standardization needs with respect to India specific requirements for Unified, Secure & Resilient ICT Backbone for Smart Cities". To this end, the report reviews a wide range of standards produced by ISO, IEC, ITU, and ETSI, as a basis for developing national policies. The study covers last-mile communication for machine-to-machine and Internet of Things applications in smart cities, common service layer requirements in ICT architecture for smart infrastructure, and comprehensive ICT reference architecture for smart cities and smart infrastructure.

The third study (Smart City Standards Normung für die nachhaltige Entwicklung von Städten und Kommunen, 2015) took place as part of the Smart City STANDARDS project, which aims to "support standardization processes for the sustainable development of cities and municipalities and to involve the key stakeholders and actors in these processes" (Austrian Society for Environment and Technology, 2015). The study categorized sets of indicators at the national and international levels, analyzed them using a focused group and presented recommendations concerning the indicator systems and their applications and standardization. Based on the results, (Tritthart, Thielen, Storch, Schrattenecker, & Purker, 2015) delineates a standardization process and provides recommendations related to smart cities in Austria.

These three studies demonstrate that countries pursue efforts to assess international standards and policies to lay the foundations for their national and local policies. The work documented in this chapter is comparable and complimentary to such efforts. The main difference is the scope. Given the vast numbers and sector-specificity of existing standards, each country has to focus on the sectors they wish to prioritize. The research presented here aims at landscaping international standards and policy recommendations for smart sustainable cities. The results could be used as a basis for such national efforts.

Policy Documents

The current section presents the identified international standards and policy guidelines that support the development and management of various aspects of smart sustainable cities, published by ISO, ITU, ETSI, European Commission, UNESCWA, and the BRICS country group. The reviewed documents are: 1) ISO/IEC JTC1 Smart Cities—Preliminary Report 2014 (ISO/IEC, 2014) (Section "ISO/IEC JTC1 Smart Cities—Preliminary Report 2014"), 2) ISO 37120:2018 Sustainable development of communities—Indicators for city services and quality of life (ISO, 2018a) (Section "ISO 37120:2018 Sustainable Development of Communities—Indicators for City Services and Quality of Life"), 3) ISO 37122:2019 Sustainable cities and communities—Indicators for smart cities (ISO, 2019a) (Section "ISO 37122:2019 Sustainable Cities and Communities—Indicators for Smart Cities"), 4) other ISO standards related to smart cities (ISO, 2012a, 2012b, 2012c, 2018b) (Section "Other ISO Standards Related to Smart Sustainable Cities"), 5) ITU-T Key performance indicators related to the use of information and communication technology (ICT) in smart sustainable cities (ITU-T SG20, 2016) (Section "ITU-T Key Performance Indicators Related to the Use of ICT in Smart Sustainable Cities"), 6) ITU-T Key performance indicators related to the sustainability impacts of ICT in smart sustainable cities (ITU-T, 2016) (Section "ITU-T Key Performance Indicators Related to Sustainability Impact of ICT in SSC"), 7) ITU-T Key performance indicators for smart sustainable cities to assess the achievement of sustainable development goals (ITU, 2019) (Section "ITU-T Key Performance Indicators for SSC to Assess the Achievement of SDGs"), 8) ETSI TS 103463 Key performance indicators for sustainable digital multiservice cities (ETSI, 2017) (Section "ETSI TS 103463 Key Performance Indicators for Sustainable Digital Multiservice Cities"), 9) UNESCWA Smart cities: Regional perspectives (The Government Summit, 2015) (Section "UNESCWA Smart Cities—Regional Perspectives"), and 10) the BRICS Smart Cities Movement Recommendations (Global Policy Journal and Observer Research Foundation, 2017) (Section "BRICS Smart Cities Movement Recommendations").

ISO/IEC JTC1 Smart Cities—Preliminary Report 2014

ISO and IEC established the Joint Technical Committee 1 (JTC1) in 1987, aimed at developing, maintaining and promoting standards in the fields of Information Technology (IT) and Information and Communications Technology (ICT). JTC1 has been responsible for many critical IT standards, ranging from the MPEG video format to the C++ programming language. Within JTC1, the Study Group "Smart Cities" (SG1), established in early 2014, published Smart Cities Preliminary Report 2014 (ISO/IEC, 2014) to explore standardization opportunities for smart cities. The report describes key concepts and relevant technologies; documents technological, market, and societal requirements for standardization; analyzes current enabling technologies; and assesses the current state of the standardization activities. The report presents the starting point of the SG1 activities, and refers to the work of other standardization institutions active in the field of smart cities, in particular, the ITU-T Focus Group on Smart Sustainable Cities, ISO TMB Smart Cities Strategic Advisory Group, and ISO/TC 268.

The SG1 report includes at the beginning some open definitions of a smart city. Such definitions highlight special benefits that come from the development of smart city initiatives and the key role played by ICT. They also consider the "smartness" of a city as its ability to achieve the goals as effectively as possible. Based on the characteristics of smart cities, needs, and requirements are explicitly described. The report also documents several smart city models which are classified into simple models, mainly those that describe a smart city from a particular viewpoint; and complex models, the ones aiming at systematically describing all elements that should be present in a smart city. The baseline for the latter is the need to develop a detailed, systematic model for a city ontology that could be used across all city systems and by all city stakeholders. This would enable data to be easily shared city-wide, and to make them available with consistent APIs, so that common software components, so called building blocks, like payment system and user authentication, are provided and reused by different city information systems, and programmers can develop apps integrated with such systems by reusing the common blocks. The approach would also enable digital services developed for one city to be more easily adopted by another city. The models must facilitate data aggregation and heterogeneous system interoperability, as well as safe and secure data exchange between different environments.

From the factors described above, this report identifies the following challenges for the development of smart city standards: 1) to have a common conceptual model of the city as a system of systems; 2) to be able to manage privacy, security, resilience, data flows and other issues at a whole-system city level; 3) to be able to evaluate how well a city is using ICT to support its overall progress in becoming smarter; 4) to ensure interoperability between different city systems; 5) to ensure consistency between standards of others international bodies; and 6) to assist non-specialist city leader in understanding the complex and interrelated ICT issues and how to manage such issues to make the city progressively smarter.

Besides, different standardization-related projects under evaluation are described, including:

- ISO/IEC AWI 30146 Smart city ICT Indicators (ISO, 2019b) which includes six types of indicators for citizen services, efficient governance, live-able environments, smart facilities, information resources, and cybersecurity;
- ISO/IEC AWI 21972 Upper-level ontology for smart city indicators (ISO, 2020) provides a data model that supports the representation of city indicator definitions, defined using the Web Ontology Language (OWL). The definition of the indicators in OWL together with city data collected and represented in OWL can be used as inputs to software applications designed for measuring specific sets of indicators.

- ESPRESSO project (Systemic standardization approach to empower smart cities and communities) (Bareño, Lindner, Kempen, Klien, & Dambruch, 2016), co-funded by the EU Horizon 2020 programme, was used as a reference for preparing the SC1 report.
- The Bureau of Indian Standards published the report "Technical requirements analysis of unified, secure & resilient ICT framework for smart infrastructure" (Bureau of Indian Standards, 2017). It discusses global and Indian initiatives for smart city standardization and proposes a framework for unified standards underpinning a comprehensive ICT infrastructure of a city.

Finally, the report collects a series of indicators for smart cities (ISO/IEC, 2014): 1) ISO/TR 37150 survey—including Global City Indicators, the Green City Index series, and the Smart City ICT indicators proposed by Fujitsu; and 2) key performance indicators proposed by the ITU-T Focus Group on Smart Sustainable Cities (ITU-T FG SSC). Table 1 enumerates the measurement areas defined by such indicators.

ISO 37120:2018 Sustainable Development of Communities—Indicators for City Services and Quality of Life

Already in 2007, the World Bank (Hoornweg, Nunez, Freire, Palugyai, & Herrera, 2007) recognized that "there are thousands of different sets of city (or urban) indicators and hundreds of agencies compiling and reviewing them. Most cities already have some degree of performance measurement in place. However, these indicators are usually not standardized, consistent, or comparable (over time or across cities), nor do they have sufficient endorsement to be used as ongoing benchmarks." To address this problem, ISO developed the standard ISO 37120 (ISO, 2018a) to provide a set of indicators to measure city performance. The indicators are related to 19 groups such as economy, education, energy, finance, governance, health, transportation, and others. Table 2 summarizes the standard. The description includes two example indicators for each of the 19 groups. Details are included in https://www.iso.org/obp/ui/#iso:std:iso:37120:ed-2:v1:en.

ISO 37122:2019 Sustainable Cities and Communities—Indicators for Smart Cities

The ISO 37120 standard, described in *Section "ISO 37120:2018 Sustainable Development of Communities—Indicators for City Services and Quality of Life" (ISO,* 2018a), was quickly and broadly adopted by the global community as a reference for sustainable cities. However, the ISO/TC 268/Working Group 2

Table 1 Summary of the ISO/IEC JTC1 Smart Cities Preliminary Report 2014

Author	ISO/IEC JTC 1	
When	2015	
What	A preliminary work aimed at guiding the standardization processes on smart cities at ISO/IEC JTC 1. The report contains: • Smart city definitions and models • Requirement assessment for smart city standardization • Review of related technologies • Review of current standardization efforts The set of indicators identified and the areas measured by them include:	
	1. ISO /TR 37150 survey—Global City Indicators	
	• Education • Fire and emergency response • Health • Recreation • Safety • Solid waste • Transportation • Wastewater • Water • Energy	• Finance • Governance • Urban planning • Civic engagement • Culture • Economy • Environment • Shelter • Social equity • Technology and innovation
	2. ISO /TR 37150 survey—The Green City Index series	
	• CO_2 • Energy • Buildings • Transport	• Waste and land use • Water • Air quality • Environmental governance
	3. Smart City realized by ICT (proposed by Fujitsu)	
	• Service • Environmental impact • Energy	• Biodiversity • Water
	4. Key performance indicators from ITU-T FG SSC	
	• Network facilities • Information facilities • Environment • Building • Energy and natural resources • Innovation • Knowledge economy • Governance	• Transportation • Security and safety • Sanitation • Healthcare • Education and training • Openness • Participation in public life • Convenience and comfort
Where	Worldwide	

dedicated to city indicators identified the need to add the indicators specific to smart cities. Thus, in 2019, they defined the ISO 37122 Indicators for Smart Cities (ISO, 2019a). This set of indicators is structured around the same 19 areas as the previous one but includes additional 79 indicators. Table 3 summarizes the standard.

Table 2 Summary of the ISO 37120:2018 standard, Sustainable cities and communities—Indicators for city services and quality of life

Author	ISO	
When	2018	
What	The standard defines 120 indicators for measuring the performance of sustainable cities and communities. The indicators are grouped into 19 areas:	
	1. Economy	• City's unemployment rate • Youth unemployment rate
	2. Education	• Percentage of females enrolled in schools • The primary education student-teacher ratio
	3. Energy	• Total end-use energy consumption per capita • Percentage of energy derived from renewable sources
	4. Environment	• Fine particulate matter (PM2.5) concentration • Particulate matter (PM10) concentration
	5. Finance	• Capital spending as a percentage of total expenditures • Tax collected as a percentage of the tax billed
	6. Governance	• Women as a percentage of total elected officials to a city office • Voter participation in the last municipal elections
	7. Health	• Average life expectancy • Number of physicians per 100,000 population
	8. Housing	• Percentage of population living in inadequate housing • Number of homeless per 100,000 population
	9. Population	• Percentage of population living below the poverty line • Gini coefficient of inequality
	10. Recreation	• Square meters of public indoor recreation space • Square meters of public outdoor recreation space
	11. Safety	• Number of firefighters per 100,000 population • Number of police officers per 100,000 population
	12. Solid waste	• Total collected municipal solid waste per capita • Percentage of the city's solid waste that is recycled
	13. Sport and culture	• Number of cultural institutions and sporting facilities • The annual number of cultural events per 100,000
	14. Telecommunication	• Number of internet connections per 100,000 • Number of mobile phone connections per 100,000
	15. Transportation	• Kilometers of public transport system per 100,000 • The annual number of public transport trips per capita
	16. Agriculture	• Total urban agricultural area per 100,000 population • Percentage of city population undernourished
	17. Urban planning	• Green area (hectares) per 100,000 population • Jobs–housing ratio
	18. Wastewater	• Population served by wastewater collection • The compliance rate of wastewater treatment
	19. Water	• Population with potable water supply service • Total domestic water consumption per capita
Where	Worldwide	

Table 3 Summary of the ISO 37122:2019 standard, Sustainable cities and communities—Indicators for smart cities

Author	ISO
When	2019
What	The standard defines 79 indicators for measuring the performance of smart cities. The indicators are grouped into the same 19 areas as the set on indicators included in the ISO 37120:2018 (see Table 2)
Where	Worldwide

Other ISO Standards Related to Smart Sustainable Cities

We can use the ISO standards to tackle many urban challenges while supporting the development and measurement of sustainable development efforts. In particular, many individual ISO standards affect or are related to the characteristics of smart cities, and can be used to monitor their technical and functional performance. Examples of ISO Standards contributing to smart cities include but are not limited to:

- The ISO 39001:2012 standard "Road Traffic Safety (RTS) Management Systems—Requirements with Guidance for Use" (ISO, 2012a) can help reduce death and serious injuries due to road accidents. According to the World Health Organization, "Traffic injuries claim more than 1.2 million lives each year and have a huge impact on health and development. They are the leading cause of death among young people aged between 15 and 29 years, and cost governments approximately 3% of GDP" (WHO, 2015). In particular, ISO 39001 contributes indirectly to smart mobility assessment.
- The ISO 20121 standard "Event Sustainability Management System" (ISO, 2012b) was developed to assist organizations in the events-related industry in improving the sustainability of their activities, products, and services. The 2012 Olympic Games in London complied with this standard, providing a strong assurance to the success of the event within the smart city concept.
- The ISO 50001 standard "Energy Management System" (ISO, 2018b) helps organizations use energy more efficiently and at reduced costs. The standard "provides a framework of requirements for organizations to develop a policy for more efficient use of energy, fix targets and objectives to meet the policy, use data to better understand and make decisions about energy use, measure the results, review how well the policy works, and continually improve energy management" (ISO, 2018b).
- The ISO 13153:2012 standard "Framework of the design process for energy-saving single-family residential and small commercial buildings" (ISO, 2012c) is a design framework for energy saving for single-family residential and small commercial buildings. It helps architects and designers develop energy-efficient buildings well suited to their locations. The standard contributes to developing smart houses.
- The ISO 16813:2006 standard "Building Environment Design—Indoor Environment—General Principles" (ISO, 2012d) focuses on the design of

Table 4 Other ISO standards related to smart sustainable cities

Author	ISO
When and what	• The ISO 39001:2012 Road Traffic Safety (RTS) Management Systems standard includes requirements with usage guidance for assessing smart mobility. 2012 • The ISO 20121 Event Sustainability Management System standard assists organizations in the events-related industry in improving the sustainability of their activities, products, and services. 2012 • The ISO 50001 Energy Management System (ISO, 2018b) standard helps organizations enhance the use of energy, using it more efficiently and at reduced costs. 2018 • The ISO 13153:2012 standard helps architects and designers develop energy-efficient buildings well suited to their locations, contributing to the development of smart houses. 2012 • The ISO Technical Committee (ISO/TC) 205 publishes standards offering an integrated methodology for the design of high-performance indoor environments, for example, the ISO 16813:2006 Building Environment Design—Indoor Environment—General Principles standard. 2012
Where	Worldwide

high-performance indoor environments. The standard "establishes the general principles of building environment design taking into account healthy indoor environment for the occupants, and protecting the environment for future generations" (ISO, 2012d) (Table 4).

ITU-T Key Performance Indicators Related to the Use of ICT in Smart Sustainable Cities

The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of the International Telecommunication Union specialized in the study of technical, operating, and tariff questions related to telecommunications. It issues recommendations in the areas of their specialization, intended at standardizing telecommunications on a worldwide basis. In 2016, ITU-T proposed a set of Key Performance Indicators (KPIs) focusing on ICT and its contribution to smart sustainable cities (SSCs). The indicators are classified based on the identified dimensions and subdimensions characterizing SSCs, which are applied to several ITU-T standards, including those described in this and the following two sections.

The Recommendation ITU-T Y.4901/L.1601 on KPIs related to the use of ICT in SSCs (ITU-T SG20, 2016) groups the indicators into six dimensions: 1) ICT, 2) Environmental Sustainability, 3) Productivity, 4) Quality of life, 5) Equity and social inclusion, and 6) Physical infrastructure; and 20 subdimensions. The ICT dimension measures: networks and access, services and information platforms, information security and privacy, and the electromagnetic field. The Environmental Sustainability dimension measures: the air quality, and water, soil, and noise. The Productivity dimension measures: capital investment, trade, innovation, and

Table 5 Summary of the ITU-T Y.4901/L.1601 Recommendation on KPIs for ICT use in SSCs

Author	ITU				
When	2016				
What	The indicators were defined in the six dimensions and subdimensions as follows:				
	Dimension		**Subdimension**		
	D1	ICT	D1.1	Network and access	
			D1.2	Services and information platforms	
			D1.3	Information security and privacy	
			D1.4	Electromagnetic field	
	D2	Environmental sustainability	D2.1	Air quality	
			D2.5	Water, soil, and noise	
	D3	Productivity	D3.1	Capital investment	
			D3.4	Trade	
			D3.8	Innovation	
			D3.9	Knowledge economy	
	D4	Quality of life	D4.1	Education	
			D4.2	Health	
			D4.3	Safety and security of public places	
			D5.3	Openness and public participation	
			D5.4	Governance	
	D6	Physical infrastructure	D6.1	Connection to services—Piped water	
			D6.2	Connection to services—Sewage	
			D6.3	Connection to services—Electricity	
			D6.8	Connection to services—Road infrastructure	
			D6.11	Building	
Where	Worldwide				

knowledge economy. The Quality of Life dimension measures: education, health, safety and security of public places, openness and public participation, and governance. Finally, the Physical Infrastructure dimension measures: connections to piped water, sewage, electricity and road infrastructure, and buildings. Because of the sharing of dimensions by the three standards, some subdimensions are numbered nonconsecutively. See Table 5.

The KPIs were selected based on six principles: 1) comprehensiveness—the indicators should cover all aspects of SSCs; 2) comparability—the indicators should be comparable for the same city over time and space; 3) availability—the indicators should be quantitative and the current and historical data should be either available or easy to collect for them; 4) independence—the definitions of the indicators in the same dimension should be almost orthogonal; 5) simplicity—the concept of each indicator should be simple and easy to understand; and 6) timeliness—producing the indicators that respond to the emerging issues in SSC construction and management should be possible.

The ITU-T KPIs were applied by several cities to measure the contribution of ICT to the development of smart sustainable cities. The Dubai experience is documented in (Torres, Guzmán, Smiciklas, and Cash, 2017) and the Singapore experience in (Smiciklas, Ashirangkura, Hyodo, Walker-Turner, and Xu, 2017).

ITU-T Key Performance Indicators Related to Sustainability Impact of ICT in Smart Sustainable Cities

The Recommendation ITU-T Y.4902/L.1602 on KPIs related to the sustainability impact of ICT on SSCs (ITU-T, 2016) presents the KPIs that measure the impact of ICT on city sustainability. The aim is to help cities and their stakeholders understand the degree to which their efforts contribute to the development of SSCs. The indicators are grouped into dimensions in Table 5 with the same or added subdimensions shown in Table 6. For example, the Environmental Sustainability dimension includes indicators in subdimensions of air quality, CO_2 emissions, energy, and water, soil and noise. The Productivity dimension comprises indicators for capital investment, employment, inflation, savings, export and import, household income and compensation, and innovation. The Quality of Life dimension measures education, health, and the safety and security of public places. The Equity and Social Inclusion dimension measures inequality of income and consumption, social and gender inequality of access to services and infrastructure, and openness and public participation. Finally, the Physical Infrastructure dimension measures connections to piped water, sewage, electricity, health infrastructure, and transport.

ITU-T Key Performance Indicators for Smart Sustainable Cities to Assess the Achievement of Sustainable Development Goals

The recommendation ITU-T Y.4903/L.1603 (ITU-T SG20, 2017) developed jointly by ISO and the UN agencies, such as UNECE, provides KPIs and guidelines for SSC developers on how to pursue the achievement of Sustainable Development Goals. We classify the indicators by area, topic, and type. Areas include economy, environment, and society and culture. Topics collect groups of indicators that describe a development area. Each indicator is assigned one topic. The indicator type describes the applicability of the indicator itself, either core global indicators for all cities or optional indicators available in “smarter” cities only. Table 7 shows the topics covered in each area.

Table 6 Summary of the Recommendation ITU-T Y.4902/L.1602 on KPIs related to sustainability impact of ICT in SSCs

Author	ITU				
When	2016				
What	The indicators were defined in the following six dimensions and subdimensions:				
	Dimension		**Subdimension**		
	D2	Environmental sustainability	D2.1	Air quality
			D2.2	CO_2 emissions
			D2.3	Energy
			D2.5	Water, soil, and noise
	D3	Productivity	D3.1	Capital investment
			D3.2	Employment
			D3.3	Inflation
			D3.5	Savings
			D3.6	Export/import
			D3.7	Household income and compensation
			D3.8	Innovation
	D4	Quality of life	D4.1	Education
			D4.2	Health
			D4.3	Safety and security of public places
	D5	Equity and social inclusion	D5.1	The inequity of income and consumption (GINI index)
			D5.2	Social and gender inequity of access to services
			D5.3	Openness and public participation
	D6	Physical infrastructure	D6.1	Connection to services—Piped water
			D6.2	Connection to services—Sewage
			D6.3	Connection to services—Electricity
			D6.6	Connection to services—Health infrastructure
			D6.7	Connection to services—Transport
Where	Worldwide				

ETSI TS 103463 Key Performance Indicators for Sustainable Digital Multiservice Cities

The European Telecommunications Standards Institute (ETSI) published the standard TS 103463 "Key Performance Indicators for Sustainable Digital Multiservice Cities" (ETSI, 2017) that defines the indicators for measuring smart cities in Europe. The standard relies on CITYKeys, an EU Horizon 2020 project that developed a framework of indicators for smart city project evaluation (Bosch et al., 2017).

The CITYkeys framework is underpinned by three dimensions of sustainability—social, environmental, and economic, and comprises two sets of indicators. One set is for measuring smart city projects and establishing their potential for propagation, which is to determine the prospects of upscaling and applying in other

Table 7 Summary of the ITU-T Y.4903/L.1603 Recommendation on KPIs for assessing the contribution of SSCs to SDGs

Author	ITU				
When	2016				
What	The indicators were defined in the following four areas:				
	Area		**Topic**		
	1.	Economy	T1.1	ICT infrastructure
			T1.2	Innovation
			T1.3	Employment
			T1.4	Trade—e-commerce (additional)
			T1.5	Productivity
			T1.6	Infrastructure—Water supply
			T1.6	Infrastructure—Electricity supply
			T1.6	Infrastructure—Health infrastructure (additional)
			T1.6	Infrastructure—Transport
			T1.6	Infrastructure—Road infrastructure (additional)
			T1.6	Infrastructure—Building (additional)
			T1.6	Infrastructure—Urban planning and public space (add.)
			T1.7	Public sector (additional)
	2.	Environment	T2.1	Air quality
			T2.2	Water and sanitation
			T2.3	Noise
			T2.4	Environmental quality
			T2.5	Biodiversity
			T2.6	Energy
	3.	Society and culture	T3.1	Education
			T3.2	Health
			T3.3	Safety—Disaster relief
			T3.3	Safety—Emergency
			T3.3	Safety—ICT
			T3.4	Housing
			T3.5	Culture
			T3.6	Social inclusion
Where	Worldwide				

contexts. The second set is for measuring smart cities themselves. The first set contains five categories: people, planet, prosperity, governance, and propagation. The second set contains the first four categories only since propagation is only relevant at the project level.

Regarding the categories, the People category refers to the long-term attractiveness of cities for a wide range of inhabitants and users. It employs the following themes: health, safety, access to services, education, diversity and social cohesion, quality of housing, and the built environment. The Planet category refers to the care of the city environment, such as water care and cleaning of the public spaces, among others. The category is further divided into energy and mitigation; materials, water, and land; climate resilience; pollution and waste; and ecosystem. The Prosperity category contributes to measuring the prosperity and equity in the society and supporting affordable, green and smart solutions. It entails the themes of employment, equity, green economy, economic performance, innovation, attractiveness, and competitiveness. The Governance category measures the process and success in project implementation, the efficiency of administration, and whether the democracy at the city level can engage citizens. This category contains the organization, community involvement, and multilevel governance themes. The Propagation category refers to the ability of replicating smart city project solutions to other locations and improving the scalability of such solutions on a wider scale. Replicability and scalability are the themes. The categories and themes are shown in Table 8.

Table 8 Summary of the CITYkeys indicators for smart city projects and smart cities

Author	CityKeys project (co-funded by the European Commission within the H2020 Programme)			
When	2017			
What	Two sets of indicators were defined for measuring: a) smart city projects and b) smart cities. The former includes the five categories described below, while the latter defines the indicators for the first four categories only.			
	Category		**Theme**	
	1.	People	T1.1	Health
			T1.2	Safety
			T1.3	Access (to other services)
			T1.4	Education
			T1.5	Diversity and social inclusion (project level only)
			T1.6	Quality of housing and the built environment
	2.	Planet	T2.1	Energy and mitigation
			T2.2	Materials, water, and land
			T2.3	Climate resilience
			T2.4	Pollution and waste
			T2.5	Ecosystem
	3.	Prosperity	T3.1	Employment
			T3.2	Equity
			T3.3	Green economy
			T3.4	Economic performance
			T3.5	Innovation
			T3.6	Attractiveness and competitiveness
	4.	Governance	T4.1	Organization
			T4.2	Community involvement
			T4.3	Multilevel governance
	5.	Propagation	T5.1	Replicability and scalability (project level only)
			T5.2	Factors of success (for project level only)
Where	Europe			

The definitions of the indicators fulfill the principles of (Bosch et al., 2017): 1) relevance—the indicators should be meaningful for the evaluation of the process; 2) completeness—the indicators should cover all aspects considered; 3) availability—data for the indicators should be easily available; 4) measurability—the indicators should be able to provides as objective measures as possible; 5) reliability—the definitions of the indicators should be clear and unambiguous; 6) familiarity—the indicators should be easy to understand by their users; 7) nonredundancy—different indicators within the framework should not measure the same aspect; and 8) independence—small changes in the measurement of an indicator should not impact preferences assigned to other indicators in the evaluation.

UNESCWA Smart Cities—Regional Perspectives

The policy report (The Government Summit, 2015), produced by UNESCWA, analyzes 90 cities in the Arab region and their capacity for becoming smart cities. The document is oriented on political leaders and policymakers, it includes recommendations for planning strategic goals to transform a city into a smart city considering the regional context. Cities were classified based on three aspects that would affect the transformation process: a) financial resourcefulness—20 cities among 90 examined, 22%; b) history—60 cities older than 1000 years, 67%; and c) poverty—80 cities requiring financial support, 89%.

From the analysis, considering policies, strategies, and challenges that emerge from the economic, environmental, and infrastructure assessment of the cities, the study formulates three rules and four recommendations, which are presented below and summarized in Table 9.

The rules are (The Government Summit, 2015):

1. The transformation should proceed toward more comprehensive work within sectors rather than on many sectors, meaning prioritizing vertical rather than horizontal transformations. This rule promotes the execution of small and specific projects for transforming a sector of a city into a smarter one. The approach requires fewer resources for implementation.
2. The leading executive role in the transformation should be played by the partnership between academia and the private sector, while the city government should act as a steering and coordinating body. This rule takes into account the high political instability of the local governments in the Arab cities and their weaknesses that cause delays, bureaucracy, conflicts of interest, and other difficulties that city transformations typically face.
3. Strategic and long-term partnerships of the city administrations with their counterparts in other cities in the region, especially on technology issues, is highly advised. One of the main guarantees of sustainability is for city administrations to enter into long-term strategic partnerships focused on conducting similar projects with other cities in the region.

Table 9 Summary of the UNESCWA rules and recommendations for smart cites in the Arab region

Author	UNESCWA
When	2015
What	The study assesses 90 cities in the Arab world and proposes three rules and four recommendations to transform them into smart cities, as summarized below. Rules: 1. The transformation should proceed toward more comprehensive work on individual sectors rather than on many sectors (vertical rather than horizontal) 2. The leading executive role of the transformation should be played by a partnership between academia and the private sector, with city governments acting as steering and coordinating bodies 3. The strategic and long-term partnerships of the city administrations with their counterparts in other Arab cities in the region, especially for technology issues, is highly advised Recommendations: 1. Conduct a classification of cities and a selection process 2. Assess the current city status 3. Follow a piece-wise development 4. Pursue inter-regional cooperation Besides, the document defines six dimensions to consider for smart Arab cities: 1) economy, 2) people, 3) city government, 4) mobility, 5) environment, and 6) living
Where	Arab region

The recommendations include (The Government Summit, 2015):

1. *Conducting a classification of cities and a selection process*—It includes preparing an extensive list of major cities in the region with indicators such as population, history, GDP, number of residents, number of industries, number of academic institutions, infrastructure, basic service, and others. Based on such information, select the cities, their priority areas, and the sectors to be transformed within each city, and define proper metrics and indicators for such sectors. Subsequently, identify the resources required for conducting the needed changes.
2. *Assessing the current city status*—The assessment should be done in two stages. The first is a general survey assessing the policies and development strategies that are adopted for six pillars: 1) economy, 2) people, 3) city government, 4) mobility, 5) environment, and 6) living. The second stage, considering the results, identifies areas where smart applications can be developed.
3. *Following a piece-wise development*—It includes developing a task force of the stakeholders to undertake a study to identify processes, data and infrastructure to conduct project work; provide a study of possible piece-wise development by identifying vertical components such as smart services, sectoral policies, and enhancements and developments of utility and infrastructure services; and packaging the efforts into a strategic plan to develop a set of smart city projects.
4. *Pursuing inter-regional cooperation of Arab cities*—Establish a group of people, including knowledgeable professionals and experts in the region, to acts as a think-tank for regional cooperation by the Arab cities. The group should develop a cooperation framework for smart cities in the Arab world and play an advisory role in such cities and their cooperation.

BRICS Smart Cities Movement Recommendations

BRICS comprises five most important emerging or recently industrialized economies of the world—Brazil, Russia, India, China, and South Africa—. For the past years, the BRICS countries are cooperating on numerous matters of mutual interest. An important issue is the transformation of cities into smart cities. In (Global Policy Journal and Observer Research Foundation, 2017), several recommendations for smart city development are suggested based on the experience and lessons learned by several BRICS cities. The proposed recommendations would help with smart city policymaking in different areas, such as local expertise, partnerships, resilience, financing, mobility, and deployment and adoption of ICT, among others.

The policy recommendations (Global Policy Journal and Observer Research Foundation, 2017) comprises those listed below and summarized in Table 10:

1. *Establish specialized entities, sponsor programs, and industry alliances*—The aim is to institutionalize a governance model and ensure broad stakeholder participation.

Table 10 Summary of the BRICS policy recommendations for smart city development

Author	Rumi Aijaz (Editor), Global Policy Journal and Observer Research Foundation (Publisher)
When	2017
What	18 policy recommendations are classified in the following areas: 1. Governance • *Establish specialized entities, sponsor programs, and industry alliances* (R1) • *Engage more with non-state actors* (R3) • *Build resilience by capturing and attending to city diversity* (R4) • *Systematize spatial data and interactions among stakeholders* (R14) • *Facilitate citizen engagement with government through social media* (R16) 2. Capacity-building. • *Improve the expertise of local bureaucracies through training* (R2) • *Mobilize funds from a combination of sources* (R5) • *Create career opportunities for the jobless* (R6) • *Create international friendship parks* (R9) • *Map built-up structures and infrastructure networks* (R18) 3. Innovation • *Build innovation hubs* (R7) 4. Environment • *Create biophilic cities* (R8) 5. Quality of life • *Ensure public safety* (R10) • *Facilitate travel for disadvantaged groups* (R11) 6. ICT • *Increase ICT penetration* (R12) • *Use digital technologies judiciously* (R13) • *Create online data platforms* (R14) • *Use GIS and rational guidelines for the provision of social facilities* (R17)
Where	BRICS countries

2. *Improve the expertise of local bureaucracies through training*—It raises the need for building human capacity to assist in the development of successful urban projects.
3. *Engage more with non-state actors*—The identification of and engagement with committed nongovernment and private sector organizations that work toward people's welfare is important for urban restructuring processes.
4. *Build resilience by capturing and attending to city diversity*—City plans should consider and leverage their social and cultural diversity and address the special needs of the critical urban sectors, for instance, housing for the poor, flooding, and many others.
5. *Mobilize funds from a combination of sources*—Different modes and sources of funding, for instance, government grants, private sector funds and bank loans should be explored.
6. *Create career opportunities for the jobless*—Unemployed youth should be able to register in government databases to be identified and able to receive specialized services, like training, awareness of job opportunities, and others.
7. *Build innovation hubs*—The availability of public spaces where local stakeholders can discuss problems and find suitable solutions.
8. *Create biophilic cities*[6]—City planning should consider and carefully integrate nature-related issues, such as the development of green areas, green buildings, etc. Greater emphasis should be put on maintaining a balance between ecological security and economic development.
9. *Create international friendship parks*—Parks can be seen as places where artists, students, architects, designers, and other actors can join, share their creativity, and promote peace and friendship.
10. *Ensure public safety*—It highlights the prioritization of safety for all citizens of smart cities. This highlight includes raising human and institutional capacity on safety-related issues.
11. *Facilitate travel for disadvantaged groups*—The formulation and implementation of rational public transport policies that help low-income workers spend no more than a fixed percentage, for example, 6% of their salary, on public transport to commute to work.
12. *Increase ICT penetration*—Motivate the development of digital mobile-based citizen services and the deployment of video surveillance systems, and other emerging technologies in the city.
13. *Use digital technologies judiciously*—Assess and leverage the embeddedness of technology in modern life to simplify service processes. Also, design new

[6] "A biophilic city is more than simply a biodiverse city. It is a place that learns from nature and emulates natural systems, incorporates natural forms and images into its buildings and cityscapes, and designs and plans in conjunction with nature. A biophilic city cherishes the natural features that already exist but also works to restore and repair what has been lost or degraded", from "Biophilic Cities", by Timothy Beatly, ISBN: 9781597267144, https://islandpress.org/books/biophilic-cities, last visited 2020-02-01.

business models for digital financial services, like crowdfunding, peer-to-peer lending, micro-savings, and others.

14. *Systematize spatial data and interactions among stakeholders*—Promote the tools for systematizing available spatial data and interactions among actors, aimed at anticipating public policy outcomes.
15. *Create online data platforms*—The provision of online platforms containing up-to-date open data related to human development—demography, health, education, income, etc. Such data can help in understanding and effectively responding to urban inequalities.
16. *Facilitate citizen engagement with government through social media platforms*—The use of social media can stimulate citizen participation in local decisions, contributing to improved governance, higher inclusion, and higher quality of life.
17. *Use GIS and rational guidelines for the provision of social facilities*—The utilization of GIS tools assists in the planning and location of new strategic places in cities to maximize impact.
18. *Map built-up structures and infrastructure networks*—The survey of buildings and infrastructure networks, such as water, electricity, or gas, helps in the needed reconstruction processes.

Analysis and Discussion

This section aims to analyze, compare, and discuss international standards and policy guidelines for smart sustainable cities, the former presented in Sections "ISO/IEC JTC1 Smart Cities—Preliminary Report 2014" to "ETSI TS 103463 Key Performance Indicators for Sustainable Digital Multiservice Cities", and the latter in Sections "UNESCWA Smart Cities—Regional Perspectives" and "BRICS Smart Cities Movement Recommendations". Section "Analysis of International Standards" is dedicated to international standards, Section "Analysis of International Policy Guidelines" to international policy guidelines, while Section 5.3 carries out a discussion on the findings.

Analysis of International Standards

We start by making the names used in various measurement areas consistent. As shown in Section "Policy Documents", the ITU and ETSI standards apply two levels of indicators, while the ISO standards apply one level of indicators. The ITU standards call them dimensions and subdimensions, while the ETSI standards call them areas and topics. To make such names uniform, we call the first level dimensions and the second level themes.

We compare the dimensions applied by all standards based on four pillars of sustainable development—social, economic, environmental, and institutional (Estevez et al., 2016). As shown in Table 11, the standards cover all four pillars. The ISO dimensions are more detailed since they aggregate the indicators at one level. The intervention areas are those that measure: a) better life for residents in the social dimension, which is education, health, inclusion, access to basic services, recreation, sport and culture, and safety; b) economic development including economy, finances, agriculture, energy, telecommunications and productivity; c) environmental protection through clean energy, use of water, and taking care of water waste and solid waste. Finally, the institutional pillar is represented by governance and urban planning. This dimension is present for ISO and ETSI but not for ITU standards, which include governance under the equity and social inclusion dimension, at the theme level.

Comparing the themes measured by the indicators in the ISO set (Section "ISO/IEC JTC1 Smart Cities—Preliminary Report 2014"), three areas are addressed by all of them—energy, water, and environment. In the case of environment, Global City Indicators consider environment-related issues in general, the Green City Index focuses on environmental governance, while Smart City ICT Indicators on environmental impact. Also, two standards cover the area of waste: the Global City Indicators consider separately solid waste and water waste, while the Green City Index refers jointly to waste and land use.

Analyzing the KPIs defined by ISO (Sections "ISO 37120:2018 Sustainable Development of Communities—Indicators for City Services and Quality of Life" and "ISO 37122:2019 Sustainable Cities and Communities—Indicators for Smart

Table 11 Comparison of measured dimensions by the ISO, ITU and ETSI standards

	ISO	ITU	ETSI
Social	Education Health Housing Population Recreation Safety Sport and culture Transportation	Quality of life Equity and social inclusion Physical infrastructure Society and culture	People
Economy	Agriculture Economy Energy Finance Telecommunication	ICT Productivity Economy	Prosperity Propagation
Environment	Energy Environment Solid waste Water waste Water	Environmental sustainability Environment	Planet
Institutional	Governance Urban planning	*Not considered as the primary dimension*	Governance

Cities") and the KPIs defined by ITU including ITU-T FG SSC (Section "ISO/IEC JTC1 Smart Cities—Preliminary Report 2014") and the standards presented in Sections "ITU-T Key Performance Indicators Related to the Use of ICT in Smart Sustainable Cities", "ITU-T Key Performance Indicators Related to Sustainability Impact of ICT in SSC" and "ITU-T Key Performance Indicators for SSC to Assess the Achievement of SDGs", six themes are included in all of them: 1) education, 2) environment, 3) energy, 4) health, 5) safety, and 6) waste and sanitation. Besides, four of the standards consider governance and water. However, the standards consider different aspects of these areas, as shown in Table 12.

Considering the themes measured by the three ITU-T KPIs (Sections "ITU-T Key Performance Indicators Related to the Use of ICT in Smart Sustainable Cities", "ITU-T Key Performance Indicators Related to Sustainability Impact of ICT in SSC", and "ITU-T Key Performance Indicators for SSC to Assess the Achievement of SDGs") and the ones applied by the ETSI standard (Section "ETSI TS 103463 Key Performance Indicators for Sustainable Digital Multiservice Cities"), we can observe several similarities. There are four common themes—education, health, innovation and safety, the last with some variations, including safety, disaster relief, emergency, etc. The ITU-T KPIs refer to infrastructure/connection to services like electricity, health, piped water, sewage and transport, while ETSI calls them access to other services. Employment is considered in two ITU-T standards (ITU-T, 2016; ITU-T SG20, 2017). Table 13 shows how standards measure other themes related to sustainable development. Three interesting themes considered by the ETSI Standard include attractiveness and competitiveness, replicability and scalability, and success factors. Such themes are not part of the ITU-T standards, which may be related to higher levels of smart city standardization in Europe compared to other regions of the world.

An exercise of putting together all themes included in the 11 reviewed standards—ISO 37120:2018 (Section "ISO 37120:2018 Sustainable Development of Communities—Indicators for City Services and Quality of Life"), ISO 37122:2019 (Section "ISO 37122:2019 Sustainable Cities and Communities—Indicators for Smart Cities"), five other SSC-related ISO standards (Section "Other ISO Standards Related to Smart Sustainable Cities"), ITU-T Y.4901/L.1601 (Section "ITU-T Key Performance Indicators Related to the Use of ICT in Smart Sustainable Cities"), ITU-T Y.4902/L.1602 (Section "ITU-T Key Performance Indicators Related to Sustainability Impact of ICT in SSC"), ITU-T Y.4903/L.1603 (Section "ITU-T Key Performance Indicators for SSC to Assess the Achievement of SDGs") and ETSI TS 103463 (Section "ETSI TS 103463 Key Performance Indicators for Sustainable Digital Multiservice Cities")—results in 206 themes in total. Figure 1 shows a word cloud comprising all of them. The word cloud highlights the main horizontal themes—infrastructure/connection to services and physical infrastructure, and safety; and vertical themes—health, education, energy, water and innovation. Other themes include governance, urban planning, air quality, transportation, and environment.

Table 12 Comparison of the areas measured by the ISO and ITU KPIs

		ITU-T			
Common area	ISO	FG SSC	Y.4901/L.1601	Y.4902/L.1602	Y.4903/L.1603
Education	Education	Education and training	Education	Education	Education
Environment	Environment and climate change	Environment	Air quality	CO_2 emissions	Air quality
Energy	Energy	Energy resources	Infrastructure/connection-to-services electricity	Energy	Energy
Health	Health	Healthcare	Health	Health	Health
Safety	Safety	Security and safety	Safety and security public places	Safety and security public places	Safety and disaster relief Safety and emergency Safety of ICT
Sanitation	Wastewater	Sanitation	Infrastructure/connection-to-services sewage	Infrastructure/connection-to-services sewage	Water and sanitation
Governance	Governance	Governance	Governance	Openness and participation	*(not considered)*
Water	Water	*(not considered)*	Water, soil, and noise	Water, soil, and noise	Physical infrastructure water-supply

Table 13 Comparison of the themes measured by ITU and ETSI KPIs

	ITU-T Y.4901/L.1601	ITU-T Y.4902/L.1602	ITU-T Y.4903/L.1603	ETSI
Economy	Knowledge-economy Trade	Capital investments Household income/compensation Export/import Inflation	Employment Productivity Trade e-Commerce	Economic performance Green economy
Environment	Air quality Water, soil, noise	Air quality CO_2 emissions Water, soil, noise	Air quality Biodiversity Environmental quality Noise Water and sanitation	Climate resilience Ecosystem Energy and mitigation Materials, water, and land Pollution and waste
Governance	Governance	Openness and public participation	(not considered)	Multilevel governance

Fig. 1 Word cloud of the themes covered by the reviewed standards

Analysis of International Policy Guidelines

The two regional policy guidelines highlight the importance of considering the local context for any city development activity. For example, the recommendations produced for the Arab region consider history for classifying cities, whether they are older than 1000 years. While such a criterion would still be valid for Europe or Asia, it would not be for cities in Latin America. Another context-dependent recommendation is assigning city governments in the Arab region with the steering but not leadership roles due to political instability. In more stable regions of the world, we can see local governments, for instance, in London, Singapore, Seoul, or New York (Smiciklas, Ashirangkura, Hyodo, Walker-Turner, and Xu, 2017), leading the smart development of their cities.

Also, the recommendations present an interesting approach for smart city development as they propose to start with a limited scope, mainly one sector to show results, and later to replicate such results to other sectors. Given the scarcity of financial and human resources in developing countries, this could be a viable approach to adopt by cities in the developing world.

The recommendations for the BRICS countries include several key success factors identified by cities in those countries, like establishing sound governance mechanisms, ensuring multi-stakeholder participation, and building human capital on both government and civil society sides.

Both recommendations call for regional cooperation and the sharing of good practices. This is valid not only at the regional level but also worldwide, as many international think tanks are implementing knowledge repositories that document case studies and good practices in smart city initiatives.

Conclusions

The evolution of smart cities toward smart sustainable cities has been accompanied by an update to the relevant standards and policy guidelines. In response, this chapter includes a summary of international standards and policy guidelines related to smart sustainable cities. In particular, we revised 15 recently published by international bodies documents related to smart sustainable cities. These documents were chosen primarily based upon their relevance, timeliness, and scope: either global (publications by ISO or ITU) or regional (publications by ETSI, UNESCWA or BRICS).

The comparison of the standards and policy guidelines highlight common intervention areas for the development of smart sustainable cities: education, health, social inclusion, environment, innovation, safety, governance, and citizen participation. ICT plays a key role in facilitating the development of any smart city service or product. Therefore, an important component of all smart city initiatives is a reliable and secure ICT infrastructure, accessible and affordable to all city residents and businesses. Despite the identified commonalities, it is clear that each city needs to define its own priorities, sectors to develop, and paths to pursue such development according to their local needs, resources, and capacities.

While the main responsibility for transforming a city into a smart city or a smart city into a smart sustainable city rests upon the local government, the local government can make limited progress alone. To deepen the transformation and embrace changes in various city sectors, cities need the expertise, capacity of and collaboration with a variety of stakeholders and actors. Also, national governments have a role to play in city development. For instance, they can help scale up smart city initiatives to reach greater numbers of residents or define policies and guidelines for cities to consistently implement such initiatives. Having national policies present several benefits, for instance defining an instrument once and applying it many times, leveraging on the bigger capacity of national governments, providing policy instruments for local governments with low capacity, and defining consistent and uniform city development paths country-wide.

Defining national or local policies for smart sustainable city development requires two major efforts—assessing the global state of the art and evaluating the state of local readiness. For both efforts, it is relevant to know what are the major international standards that the initiatives should consider. Besides, the standards serve as tools for highlighting major areas of intervention for smart city development. Thus, they are useful for defining a gap between the current and the aspiring level of development in a given area. This chapter contributes to this process by revising major international standards relevant to smart sustainable cities, as a basis for defining policies aimed at developing and managing such cities.

While pursuing community development, governments are also responsible for fulfilling international commitments like the achievements of Sustainable Development Goals or other regional development goals. Thus, for governments pursuing smart sustainable city initiatives, it is of high relevance to consider and contribute to regional policy instruments and related policies like e.g. the regional digital agendas.

We acknowledge that the literature reviewed in this work is not exhaustive. There may be other standards and policy guidelines that were not included, mainly because the intention was to uncover similarities and differences, not to be comprehensive. Our future work includes creating and maintaining an online repository of policy instruments for smart sustainable cities, to serve as a digital resource for various activities related to developing and managing such cities, for instance, for courses and educational programs that help build human capacity in this area.

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AI Regulation for Smart Cities: Challenges and Principles

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Abstract To reduce the burden on city resources and improve governance and services, artificial intelligence (AI) is being applied toward building smart cities. Although smart city AI applications bring benefits of automation and efficiency, they also raise regulatory challenges, with concerns about discrimination in service provision, privacy, legal, and ethical issues. To address these issues, we propose an integrated and systematic framework for smart city AI regulation. To develop the framework, we first identify the dimensions of a smart city and the components of AI-enabled systems. We then discuss examples of smart city AI applications and the regulatory challenges they pose. Last, we describe our integrated framework of principles for smart city AI regulation, which addresses these challenges. Our study contributes to both the literatures on smart cities and AI frameworks, as well as practice on smart city AI policy and regulation.

Keywords Smart city artificial intelligence regulation · Artifical intelligence regulation · Smart principles · Artificial intelligence policy

Introduction

Due to urbanization and the increase in city density, the burden on city resources and governance is intensifying. To alleviate such burden as well as improve the quality of life of citizens, governments are investing in advanced information and communication technologies (ICT) and applying them to various city services, which facilitates the development of "smart cities" (Jucevičius, Patašienė, & Patašius, 2014). An emerging trend in the use of ICT is the application of artificial

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_5

intelligence (AI), which has experienced a resurgence in recent years due to advances in techniques, such as natural language processing, machine learning, computer vision, and robotics. This is also aided by the increase in the amount of data available, i.e., big data, and the dramatic improvement of computing power (Russell & Norvig, 2016; Stoica et al., 2017).

These AI applications bring opportunities of automation and efficiency for smart city infrastructure and services, such as autonomous vehicles for transport, and detection and tracking of criminals for public safety. However, there is also the potential for negative implications during the development and application of AI for smart cities, such as discrimination in service provision, privacy, legal, and ethical issues (Stoica et al., 2017; Stoyanovich, Abiteboul, & Miklau, 2016). Hence it is crucial for governments to regulate the design and use of AI for smart city applications.

To address the regulatory challenges posed by AI systems and applications, government agencies, companies, and research institutes have proposed several frameworks to guide the development and use of AI (see Appendix). Among these frameworks (e.g., Accenture, 2016; European Commission, 2018; Microsoft, 2019; UK Government, 2019), the most common principles are transparency, equality or non-discrimination, accountability, and human values. Data privacy and safety principles have also gained attention in many of these frameworks (e.g. Japanese Society for AI, 2017; Microsoft, 2019). A few frameworks mention the need for responsible and sustainable use of AI systems (e.g., Accenture, 2016; PwC, 2019). However, existing frameworks generally propose guiding principles without a systematic, conceptual derivation, and integration of the principles. Additionally, the frameworks do not discuss the enforcement mechanisms to operationalize these principles. Furthermore, the principles are typically not adapted to the context of smart cities and thereby not linked to the dimensions, applications, and challenges of smart cities.

Motivated thus, we aim to understand and address these issues by developing a framework of principles for AI regulation for smart cities in a conceptual and systematic way. This can help researchers and practitioners to understand the principles for governing smart city AI applications and examine or develop policies and regulations accordingly. Specifically, our framework is built by addressing the following research questions: (1) What are the dimensions of a smart city? (2) What are the components of AI systems? (3) What are the regulatory challenges posed by smart city AI applications? (4) What principles should be followed to regulate smart city AI applications to address these challenges?

Thereby, we propose such an integrative framework for principles of smart city AI regulation, which covers input, algorithm, and outcomes of AI systems. Our framework contributes to both research and practice. Specifically, the framework adds to the literatures on smart city and AI frameworks by conceptually integrating principles of smart city AI regulation based on the identification of smart city dimensions and AI system components. Our framework proposes these principles to address the specific regulatory challenges posed by smart city AI applications in the real world. Furthermore, we discuss the enforcement mechanisms, such as regulations, for operationalizing these principles, which is overlooked in existing AI frameworks. Finally, the framework provides practitioners i.e., policy makers and companies, with a systematic set of regulation principles for governing and developing smart city AI applications.

Before we introduce the framework, we first delve into the dimensions of a smart city and understand the components of AI systems. Then we introduce several examples of smart city AI applications and discuss the regulatory challenges entailed in these applications. Finally, we propose an integrative framework taking into account smart city dimensions and AI system components, which outlines the principles for regulation of smart city AI applications.

Dimensions of a Smart City

Smart city has been referred to as an urban ecosystem that places emphasis on the use of digital technology, shared knowledge, and cohesive processes to underpin citizen benefits (Juniper Research, 2018). However, it is hard to provide a precise definition of smart city (Jucevičius et al., 2014). Nevertheless, we could deepen our understanding of the concept through investigating its dimensions. Figure 1 shows the overview of the proposed dimensions. We derive these dimensions based on the perspective of the enabling resources for smart cities, as well as the two key aspects of smart city functioning, i.e., city governance and urban life.

Specifically, a smart city is comprised of several dimensions, which could be discussed in terms of the *city functioning* and the *enabling resources*. On one hand, smart city implies the application of smart computing technologies in the subsystems of the city. For example, Dirks and Keeling (2009) identify nine city systems, i.e., transportation, energy, education, healthcare, buildings, physical infrastructure, food, water, and public safety. According to the aspects of urban life, Lombardi, Giordano,

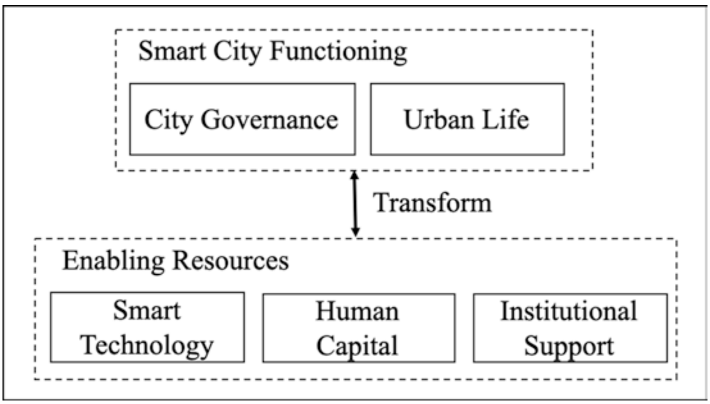

Fig. 1 Dimensions of a smart city

Farouh, and Yousef (2012) summarized six components of a smart city, i.e., smart economy for industry, smart people for education, smart governance for e-democracy, smart mobility for logistics and infrastructures, smart environment for efficiency and sustainability, and smart living for security and quality. Particularly, the former classification focuses on the *city governance* perspective, which emphasizes the management of important resources to run a smart city, while the latter views smartness from an *urban life* perspective, which highlights key areas for the growth of the smart city and the improvement of citizens' life. The further development of a smart city could go beyond the independent use of technologies in these domains and link them as an organic system to support city sustainability and better life of citizens (Albino, Berardi, & Dangelico, 2015; Nam & Pardo, 2011). Particularly, due to the interdependencies across smart city systems, joint advances in the technologies for different domains is needed. For instance, with the interconnected smart city functioning, a smart city could garner information regarding its physical infrastructure and use it to enable multiple conveniences such as facilitate mobility, conserve energy, and improve the quality of air and water (Nam & Pardo, 2011).

At the same time, a smart city development is driven by various *enabling resources* in combination (Nam & Pardo, 2011). First, *smart technology* refers to underlying intelligent IT infrastructure, systems, and applications. This includes systems with real-time awareness of the physical world and capabilities of advanced analytics to improve city infrastructure and services. Specifically, city processes can now be monitored by various approaches in real-time, such as through connected telecommunication networks, digitally controlled utility services and infrastructure, sensor and camera networks, and mobile technologies used by citizens (Kitchin, 2014). These approaches generate vast amounts of data that can be used to represent, model, and predict urban processes and simulate the likely outcomes of future urban development. With the radical improvement in computing technologies and capabilities, advanced data analytics and AI have been introduced into various city sectors to support decision-making and service provision. The combination of big data and ubiquitous intelligence together help enable a city to run in an intelligent and coordinated way (Girtelschmid, Steinbauer, Kumar, Fensel, & Kotsis, 2014).

In addition to technology, human-related resources, such as education, innovation, and learning, are also important to drive a smart city. Such *human capital* contributes to the collective intelligence and leads to a creative environment for a smart city. For example, through promoting IT education and initiating life-long learning programs, a city can not only equip its citizens with IT capabilities to utilize the services of a smart city, but also build intelligence for creating smart city innovations (Albino et al., 2015; Nam & Pardo, 2011). *Institutional support* refers to the support from government agencies and the community for governance of a smart city. The transformation through technology interacts with the political environment of the city. To transform existing cities into smart cities, government agencies not only need to provide policy and administrative support (e.g., initiatives, structure), but also to engage diverse stakeholders (e.g., citizens and companies) into the governance and facilitate the collaboration across different departments and communities (Albino et al., 2015; Nam & Pardo, 2011).

It is worth noting that smart city functioning is not only transformed by enabling resources, but is also a transformer of resources. This follows Giddens' structuration theory, which discusses the mutual interactions between technology and humans (Giddens, 1984). In other words, the development of smart city functioning could in turn facilitate the availability of enabling resources. For example, if they witness progress in city governance and improvement in urban life through applying intelligent technologies, governments, and communities would likely invest more resources into developing the technologies and thereby further promote the smart transformation of city functioning. In this sense, advances in smart city functioning could also enhance institutional support. Additionally, smart education, which is an important smart city function, could strengthen human capital by enabling more citizens to access and acquire advanced IT knowledge and resources through various channels. This would contribute to the collaborative environment for the further development of the smart city. Last, the advances in smart city functioning could lead to greater communication and interactions among different city functions, which would bring new research and development opportunities for building smart technologies.

In sum, a smart city development not only entails the adoption of intelligent computing technologies in citizen life and city governance, but also depends on human capital and the support from institutions. This in turn stimulates the production of these enabling resources.

Components of AI Systems

With regards to smart technology, AI refers to the machines or software that attempt to think and behave in a human and rational manner (Russell & Norvig, 2016). The aim of AI not only includes the successful fidelity to human performance, but also the achievement of rational or ideal performance. AI has largely been applied to reasoning, problem solving, knowledge representation, natural language processing, perceptions (e.g., face recognition, speech recognition, computer vision) and motion manipulation (e.g., robotics) (Flasiński, 2016). Figure 2 shows the components of AI systems. Particularly, we derive this figure based on an input—process—output—outcome systems view.

Similar to humans, AI systems need to capture and *input data* as the observations of the environment to make decisions and solve problems. In the past two decades, the increasing popularity of online services, such as Google Search, Amazon, and YouTube, are generating huge amounts of data in various forms, such as text, picture, video, and transactions, which can serve as inputs for AI systems. Moreover, the widespread adoption of sensors and IoT in different domains is further propelling the use of big data, where continuous data points and their network could be captured to reflect a dynamic and real-time environment. One such example is a current urban system, where different data sources are connected, such as fixed and wireless telecom networks, digitally controlled utility services, and transport infra-

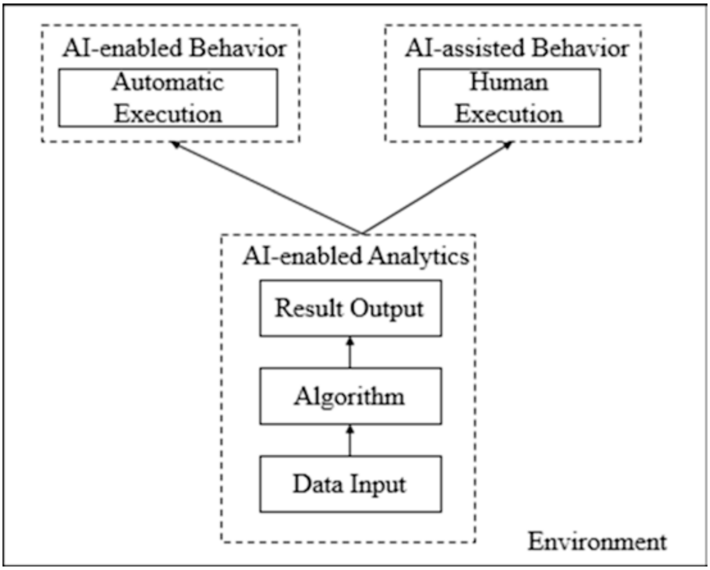

Fig. 2 Components of AI systems

structure, sensor and camera networks, building management systems, and so on. These data sources are widely used to monitor, manage, and regulate city flows and processes (Kitchin, 2014). For instance, networked cameras on roads and in public places could provide data input for AI face recognition technologies to detect and track criminals for enhancing public safety (Greene, 2018).

According to their *algorithms*, AI systems would process these inputs and generate outputs for decision-making or problem solving. Among AI algorithms, machine learning techniques have become prominent in recent years and have led to the resurgence of AI. Machine learning techniques can be divided into two types, i.e., supervised and unsupervised learning. Supervised learning involves a labeled training set, which helps systems to understand new data based on existing labels or categories. It is typically used for classification tasks. Nowadays, it is possible to acquire vast amounts of labeled data by recruiting online workers on sites such as Amazon Mechanical Turk to carry out labeling tasks, or from large online datasets, e.g., Google Open Images Dataset with more than nine million images and YouTube-8M with more than seven million labeled videos (Heath, 2018). Based on labeled data, algorithms learn how to apply these labels to new data. For example, based on previous patterns of various road obstacles, the algorithm can learn how to identify different types of road obstacles in new images or videos (Brisimi, Cassandras, Osgood, Paschalidis, & Zhang, 2016).

On the other hand, unsupervised learning identifies patterns and structures in an unlabeled data set. It is usually applied in clustering tasks. Traditional classification and regression algorithms, such as support vector machines, naïve Bayes and decision trees, fall under supervised learning, while K-means is unsupervised. For example, combining GIS information and crime data, high and low spots of crimes can be clustered such that people can easily identify locations with high or low crime rates (GIS Geography, 2018). As a subset of machine learning techniques, neural networks and deep learning methods include multiple algorithms, which could work in either a supervised or unsupervised way. Indeed, the advances in neural network and deep learning algorithms have greatly enhanced the application of AI systems to solving problems in the real world.

According to the algorithm, the system processes inputs and then generates *outputs*. The output can be in the form of information or knowledge for decision-making or problem solving, or even instructions for robotics. Based on the outputs, actions can be taken in the real world automatically (*AI-enabled*), e.g., through robots or other automatic machines, or semi-automatically (*AI-assisted*), e.g., executed by humans who use the results as references for decision-making.

Smart City AI Applications and Regulatory Challenges

Working with ubiquitous data sources provided by the Internet of Things (IoT) as well as networked databases, AI brings opportunities of automation and efficiency for smart city systems. Indeed, AI applications are being implemented or will be implemented in various aspects of a smart city (Tech Wire Asia, 2018). However, large-scale deployment of AI technologies e.g., data-driven predictive systems, may result in unintended adverse societal consequences. To illustrate the issues, we discuss smart city AI applications and regulatory challenges mainly from the US, EU, and Singapore, which is considered as a leader in AI readiness.[1]

For example, taking advantage of AI and sensors, autonomous vehicles are becoming capable of sensing their environment and navigating without human intervention (Urban Redevelopment Authority of Singapore, 2017). Developing and deploying autonomous vehicles to public transport services can reduce the burden on manpower (e.g., bus or train drivers). Further, these vehicles may help save lives overall by more strictly conforming to transportation rules than human drivers (Chessen, 2017). However, the convenience and potential brought by the automation in mobility may also lead to ethical dilemmas. One example is the trolley problem. Autonomous self-driving vehicles would need to figure out how to respond in situations where collisions are unavoidable. In such cases, the algorithm would have to decide how to minimize harm, which could pose an ethical dilemma between options such as minimizing the number of deaths or saving the driver and passengers (Nyholm & Smids, 2016). In addition to such ethical problems, autonomous self-driving cars may also lead to legal issues. One instance is the liability of accidents. When a human driver is not present, the question arises as to whether the

[1] https://www.oxfordinsights.com/ai-readiness2019.

damage caused in an accident can be attributed to the owner of the car, or whether only the manufacturer can be held accountable (Chessen, 2017).

Other autonomous machines, such as healthcare robots, share similar issues. AI-enabled robots are being developed and implemented in the departments of hospitals for tasks, such as surgery, rehabilitation, and assistance (Healthcare Asia, 2017; Khalik, 2015). Additionally, they can be used for home care of patients and the elderly (Kidal, 2017). However, though these robotics technologies can improve healthcare efficiency and reduce the burden on healthcare manpower, they may pose serious concerns for patient safety, autonomy, control, and accountability. For example, according to the US FDA, there were 144 deaths and more than 1000 injuries that involved robotic surgeons between 2000 and 2014 (Thomson, 2015). Of these, 60% accidents were caused by device malfunctions, such as out of power, incorrect movement, electrical sparks, and falling pieces (MIT Technology Review, 2015). Further, if the command to a robot would harm patient safety, such as a senior citizen requesting the robot to kill him or her, or the doctor requesting a wrong medical procedure, should the robot still carry out that command? Such scenarios raise questions about who will be responsible for the adverse outcomes of these healthcare robots (Simpson, 2016).

In addition to enabling automation, AI has also been applied to support the decision-making of various smart city functions. One such important area is public safety. The networked cameras from roads and public places provide data input for face recognition technologies to track criminals (Greene, 2018). This data source can also be connected with other data sources, such as social media, Internet use, hotel stay and trips to monitor criminals' tracks. However, the ubiquitous surveillance could make people feel vulnerable about their rights to privacy, confidentiality, and freedom of expression (Gasser & Almeida, 2017). Other serious legal and societal consequences could arise when AI is used for predictive policing crime prevention. For example, there could be racial bias due to a biased training set or algorithms in the AI system. A notable case is the COMPAS predictive policing system (Angwin, Larson, Mattu, & Kirchner, 2016). This algorithm aimed to predict recidivism in individuals detained by the police, by assigning them a 'risk score'. The algorithm was found to be heavily biased against persons of color i.e., it would consistently assign a higher risk score to people of color (even though those individuals were later found to be relatively low risk), and lower scores to white persons (though they turned out to be much likelier to commit crimes later on).

Bias in AI systems could also cause discrimination in other smart city domains. For example, by applying AI in logistics system, companies attempt to optimize their arrangement of materials and product delivery. However, reporters found that Amazon's same-day delivery service was unavailable for ZIP codes in predominantly black neighborhoods (Crawford, 2016). Further, through use of AI, businesses and advertisers have opportunities to precisely reach a target population through search engines, such as Google. However, it was found that women were less likely than men to be shown ads on Google for highly paid jobs. This biased output could be caused by the biased training dataset used for job search or the algorithm in the AI system.

The unforeseeable societal outcomes of these AI applications can be largely attributed to a key characteristic: they are typically black-box learning systems. This means that their underlying decision-making and learning mechanisms are not observable by external auditing and law enforcement agencies. What's worse, even those who design these systems often do not fully understand how certain decisions are made. State-of-the-art learning algorithms often favor precision over transparency. Indeed, in many cases there is an inherent tradeoff between transparency (how well can the system be understood by a stakeholder) and accuracy (how well can the system predict the outcomes of future inputs). Ensuring transparency in AI and machine learning has seen increased attention from government bodies (Goodman & Flaxman, 2016; Smith, 2016), legal experts (Roggensack & Abrahamson, 2016), and the media (Hofman, Sharma, & Watts, 2017; Smith, 2016).

Further, in various scenarios, activities of individual users e.g., their purchases and preferences, health data, online and offline transactions, photos they take, commands they speak into their mobile phones, locations they travel to, are used as training data. This raises issues of privacy and security regarding individual's data collected, stored, processed, shared, and output from such systems. Particularly, as AI systems typically involve cloud computing and networks for data storage, communication, and analytics, cyber threats could have serious impacts on these systems. For example, in 2017, over 99 billion records were exposed due to data breaches in cloud services (Balakrishnan, 2018).

Framework of Principles for Smart City AI Regulation

In order to resolve these issues, this chapter develops an integrative framework, which can help researchers and practitioners to understand the strategies and principles for regulating AI applications for smart cities. As discussed in the previous section (see Fig. 2), AI systems include analytics and AI-enabled or assisted behaviors. Figure 3 shows the general principles for both the *analytics* and the outcome *behaviors*.

As can be seen in Fig. 3, to support the smart city (see Fig. 1), certain principles need to be implemented by regulating both AI-based behaviors and analytics design, such as protection of human rights, ethics and fairness (Gasser & Almeida, 2017; Stoica et al., 2017). Traditionally, regulations and laws have been widely implemented to protect various *human rights*. For example, everyone shall be entitled the right to life, and no one shall be arbitrarily deprived of his or her life. In principle, AI-enabled or assisted behaviors should also not hurt human beings and violate their human rights (Etzioni, 2017). However, as existing laws and rules focus on human behaviors, adaptations need to be made to regulate AI-enabled or assisted behaviors. For example, in order to regulate self-driving car trials, the Singapore government has amended the Road Traffic Act to recognize that a motor vehicle does not necessarily have a human driver. This can exempt autonomous vehicles and their operators from existing legislation set for human driving behaviors. Instead, the operators are asked to ensure there is liability insurance, or place a

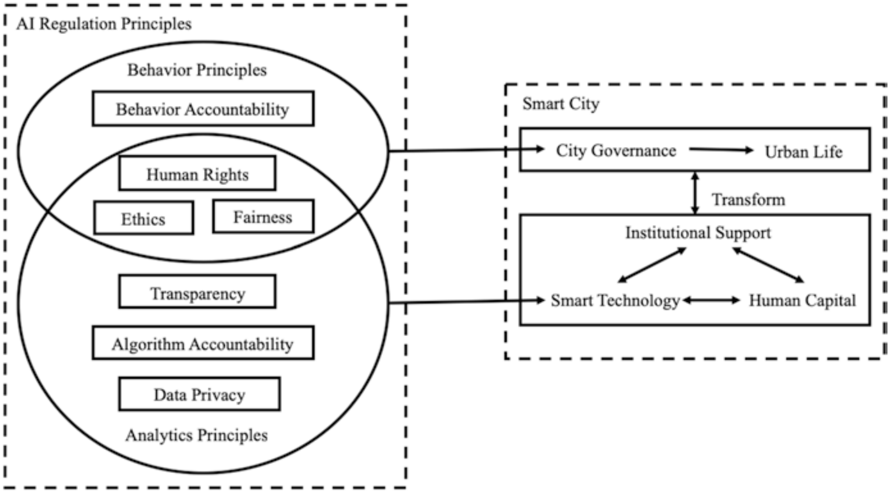

Fig. 3 Framework of principles for smart city AI regulation

security deposit (Straits Times, 2017). By explicitly defining the responsibilities of different parties in protecting human rights, this could also contribute to *behavior accountability*, which includes the clarification of liability of AI-enabled or assisted outcomes. In addition to the protection of basic human rights, the AI-enabled or assisted behaviors should also be ethical and fair (Stoica et al., 2017). For example, to alleviate concerns over bias in policing, California State has introduced a bill called the Body Cameral Accountability Act, which seeks to prohibit the use of facial recognition in police body cameras. The state has also introduced another bill to require businesses to publicly disclose their use of facial recognition technology in view of public concerns (Nonnecke & Newman, 2019).

Further, as the output of AI systems determines or influences the corresponding outcomes, conformity to these core principles of behaviors, i.e., protection of human rights, *ethics, and fairness,* would largely depend on the regulation of the AI system design. To achieve this, the design of AI systems should avoid biased data and algorithms, build rules to protect human rights, and take ethics into consideration. For example, by identifying the bias of data and algorithms in smart city AI cases, the Global Future Council on Human Rights published a white paper to propose several principles for avoiding discrimination in AI systems, such as active inclusion of the designers with diverse background, clear definition of fairness to guide system development, and visible avenues for redress for those affected by disparate impacts (Global Future Council on Human Rights, 2018). Another example is the Federal Automated Vehicles Policy in the U.S., which provides guidelines for assessing automatic vehicles before they enter the market (US Department of Transportation, 2016). The policy includes guidance applicable to all intelligent systems on the vehicle, such as privacy, system safety, crashworthiness, consumer education, and training. Further, it also provides guidance specific to different contexts, such as the operation situation, object/event detection and response, and minimal risk conditions. With clear standards and guidelines, governments and businesses can better govern their design process for ethical and fair AI applications.

In addition to compliance with the core principles, the design of AI analytics also needs to follow the specific principles of data privacy, algorithm accountability, and transparency. First, *data privacy* not only implies the rights of the data subjects to know and control how their data could be collected and used, but also the responsibility of businesses and organizations to collect and use data with the consent of the data subjects and protect the privacy of the subjects. For example, the European Union Legal Affairs Committee recommends privacy by design and privacy by default, informed consent, and encryption, as well as use of personal data need to be clarified (Guan, 2018). Moreover, the recently enforced General Data Protection Regulation (GDPR) further puts these principles into law (European Commission, 2016). Data subjects must be clearly informed of the scope of data collection, the legal basis for processing of personal data, the duration of retaining the data, the involvement of third parties, and disclosure of any automated decision-making that is made on a solely algorithmic basis. In addition, data subjects hold the privacy rights to request the information related to their data collection and use.

Second, different from behavior accountability, which refers to the general responsibilities of different parties for outcomes, *algorithmic accountability* indicates the specific responsibility of algorithm designers to provide evidence of potential or realized harms (WWW Foundation, 2017). Particularly, the potential or realized harms could not only refer to legal issues, but also include ethical concerns, such as algorithmic discrimination. Correspondingly, it is the responsibility of the designers to ensure that the algorithm is fair, explainable, auditable, accurate, and responsible. In addition to clarifying the parties accountable for harms or damages caused by algorithmic decision-making, it is also important to explicitly define who are responsible for repairing the systems to avoid future problems. In the U.S., the Algorithmic Accountability Act of 2019 has been recently proposed as the first federal legislative effort to raise awareness of potential negative impacts of implementing AI systems among various industries, such as technology companies, banking, insurance companies, and other consumer businesses (Jones Day, 2019). It authorizes and directs the Federal Trade Commission ("FTC") to issue and enforce regulations that will require certain persons, partnerships, and corporations using, storing, or sharing consumers' personal information to conduct impact assessments and address any identified biases or security issues in a timely manner.

Finally, the AI analytics design also needs to be *transparent*, which requires verification and auditing of datasets and algorithms for fairness, robustness, diversity, nondiscrimination, and privacy (Stoyanovich et al., 2016). Transparency goes beyond the demonstration of the algorithm, and requires that algorithmic decisions as well as any data driving those decisions can be explained to end-users and other stakeholders in nontechnical terms (WWW Foundation, 2017). It is a necessary component to support algorithm accountability, and has been written into several policies and regulations, such as EU's GDPR. GDPR requires that the decisions made by AI applications should be explainable to the data subjects. The challenges here could be to define a clear standard for a satisfying explanation and overcome the inherent difficulties in explaining AI algorithms (Lawton, 2018).

All the above AI policy principles contribute to a safe, fair, accountable, and transparent smart city environment. Such an environment facilitates the deployment of enabling resources (i.e., smart technology, human capital and institutional support) for the actualization of smart city functioning in various domains of city governance and urban life (Gil-Garcia, Zhang, & Puron-Cid, 2016).

Limitations and Future Work

As with other research, this study also entails a few limitations. First, though our framework is not country or region-specific, and could potentially be applied across different countries and cities, the examples we used to illustrate the smart city AI applications, challenges, and principles are mainly from cities in developed countries, such as the EU members, Singapore, and the U.S., which may limit the generalizability of our work. Future research could test the generalizability and adapt the framework to other countries and cities with different levels of economic development, legal systems, cultural norms, and degree of urbanization. For instance, instead of studying existing cities, future work could also explore the principles needed to build new smart cities from scratch in rural or semi-urban areas, which could be important for developing countries, such as India and China.

Second, our framework focuses on the principles that need to be considered by policy makers and companies to develop and implement smart city AI applications, while not comprehensively exploring the mechanisms needed to operationalize these principles and govern such applications. For example, we did not examine how power issues could be addressed between different stakeholders, such as between cities and state or national governments, between government bodies and industry, or even between big tech companies and governments, in order to implement the proposed principles. Future research could identify the governance mechanisms for smart city AI applications and integrate them with our conceptually derived framework to deepen the understanding of smart city AI governance.

Conclusion

In this chapter, we discuss smart city dimensions, AI system components, smart city AI applications and their regulatory challenges, and the principles for regulation of smart city AI. Particularly, AI applications are being implemented to support various smart city functions, while they present multiple legal or ethical issues. However, the current approach to resolve these challenges is fragmented. Therefore, we attempt to identify common principles that could help regulate AI systems for smart cities. This could assist governments and businesses to form a cohesive view toward the design and implementation of AI for smart cities.

Appendix: A Review of Major AI Governance Frameworks

Table 1 Review of major AI governance frameworks (selected from https://algorithmwatch.org/en/project/ai-ethics-guidelines-global-inventory/)

Source/principle	Transparency/ interpretability	Equality/ fairness	Accountability	Safety/ controllability	Fit with human values	Responsible use/ sustainability	Privacy/ data control	Others
(China) National New Generation Artificial Intelligence Governance Expert Committee, Laskai and Webster (2019)	–	Yes	Yes	Yes	• Harmony and friendliness	–	Yes	• Open collaboration • Agile governance
(European Union) European Group on Ethics in Science and New Technologies (2018)	–	Yes	Yes	Yes	• Human dignity and autonomy • Democracy	Yes	Yes	–
(European Union) European Commission (2018)	Yes	Yes	Yes	Yes	• Human agency and oversight • Societal and environmental well-being	–	Yes	–
(Japan) Japanese Society for Artificial Intelligence (2017)	Yes	Yes	Yes	Yes	• Contribution to humanity • Abidance of laws and regulations	Yes	Yes	–
(Singapore) Monetary Authority of Singapore (2018)	Yes	Yes	Yes	–	• Human ethics (e.g. company value, code of conduct)	–	–	–

(continued)

Table 1 (continued)

Source/principle	Transparency/ interpretability	Equality/ fairness	Accountability	Safety/ controllability	Fit with human values	Responsible use/ sustainability	Privacy/ data control	Others
(Singapore) Singapore Personal Data Protection Commission (2019)	Yes	Yes	–	Yes	• Human centric (well-being)	–	–	–
(UK) UK Government (2019) and The Alan Turing Institute (2019)	Yes	Yes	Yes	Yes	• Human dignity • Connection • Well-being • Social priorities protection	–	Yes	–
Microsoft (2019)	Yes	Yes	Yes	Yes	• Empowerment	–	Yes	–
IBM (2019)	Yes	Yes	Yes	–	• (Company) value alignment	–	Yes	–
PwC (2019)	Yes	Yes	–	Yes	–	Yes	–	• Governance
SAP (2018)	Yes	Yes	–	Yes	• Driven by (company) value • For people	–	Yes	–
Accenture (2016)	Yes	Yes	Yes	Yes	• Human centric	Yes	Yes	–
IEEE (2019)	Yes	–	Yes	–	• Human rights, well-being • Empowerment	–	Yes	• Effectiveness • Awareness of misuse • Competence
International Conference of Data Protection and Privacy Commissioners (2018)	Yes	Yes	Yes	–	• Empowerment	Yes	Yes	–
Information Technology Industry Council (2017)	Yes	–	Yes	Yes	–	Yes	–	• Robust and representative data
Dataethics (2017)	Yes	Yes	Yes	–	• Human centric	Yes	Yes	–

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Creating Public Value in Cities: A Call for Focus on Context and Capability

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Abstract Cities throughout the world are changing. To respond to these changes mayors and other urban policy makers are investing heavily in innovations aimed at making their cities "smarter." This essay presents the argument that making a city smarter rests on the capability of that city to create public value for those who live and work there. Such capability, in our view, is a function of context. Our goal in presenting this essay is to incentivize researchers and urban policy makers to systematically consider context in smart city investment decision-making. For academics and researchers, we call for new research that systematically examines the interplay between innovation, context, and public value creation in urban environments. For urban policy makers, we call for a new focus on context-informed decision-making about smart city investments.

Keywords Smart cities · Public values · City capabilities · Smart city lessons learnt · Citizen engagement · Smart city governance

Introduction

Cities throughout the world are changing. Almost any article on the global trend of urbanization presents one or another well-supported prediction about how by 2050 three quarters of the world's rapidly growing population will live in cities, up 25% from 2010 and completely reversing the population distribution between urban and rural environments. This rapid growth, researchers and practitioners agree, is increasing pressure on the physical and social infrastructure of cities and straining the basic services that make a city livable. Social problems in such cities are recog-

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_6

nized as increasingly complex and intertwined and their solutions require the collaboration of multiple city agencies, levels of government, nonprofit organizations, business, and society at large. Such livability gaps have become the focus of mayors and urban policy makers the world over and have been at the heart of smart city and urbanization research. In large part, smart city solutions put forward by industry are aimed at relieving the strain of growth on the world's cities.

De-urbanization is also changing the context of many of the world's cities and reducing livability in very different ways. While people are moving to cities, generally, to improve their quality of life, other factors are impacting cities, causing them to shrink. Three main trends are leading to de-urbanization: declining fertility rates, as being experienced in Japan, declining manufacturing and mining, as being experienced in the USA, and resource depletion and technological change, as being experienced in China (Biswas, Tortajada, & Stavenhagen, 2018). While growing cities are struggling to modernize and expand their straining infrastructures, shrinking cities are struggling to downsize their infrastructures and to find sustainable "financial models for operation and maintenance." Cities such as Sheffield, Iowa in the USA and Ostrava in the Czech Republic are increasingly focused on how to "shrink smart" (NPR, 2018). Policy makers must be clear about which strategies are right for shrinking cities and which for growing cities.

To respond to these significant and rapid changes, mayors and other urban policy makers are investing heavily in innovations aimed at generating value for those who live and work in their cities; in a word, they are working to make their cities "smarter." Increasing pressures to make a city smarter as a way to respond to these changes are causing many city leaders to look to the world's "smartest cities" for best practices. Many of these practices are based on "smart city technologies" and are driving significant investments in technical innovations in cities. According to the International Data Corporation Worldwide Smart Cities Spending Guide, "global spending on smart cities initiatives will total nearly $124 billion in 2020, an increase of 18.9% over 2019" (Yesner & Da Rold, 2020). Unfortunately, many city leaders are finding that the direct adoption of an innovation from one city to another does not guarantee the creation of public value. They are finding that the high-pressure conditions to make their cities smarter quickly make it difficult for them to fully take into account the fact that no two cities are alike (Eger, 2009) and that what works in one city may or may not be feasible in another (Gasco-Hernandez, 2018).

Cities throughout the world, whether growing or shrinking, large or small, are looking to technologies such as sensors and IoT networks as a way to capture data about city programs and services. The idea is that new data, captured by these sensors, shared across networks and used to drive analytics will help inform policy decisions in that city. Sensors collecting data on water consumption in cities, for example, are being used to help inform routine water management operations as well as more policies. In many cases, this is possible because those cities have the capability to collect and manage large volumes of data and they have sophisticated data management capabilities. Further, they have a history of evidence-based decision-making, or at the very least they already have systematized decision-making about water resources management and can now integrate the use of new analytics into those decision-making processes. In other cities, while the deployment of sensors is technically possible, capability to organize and manage the resulting data and to make it ready and available for use in sophisticated analytics in support of decision-making is at best limited, and in many cases missing. Many shrinking cities, particularly small cities are finding that while they see the potential of machine learning to provide automated decision-making support to a shrinking workforce, for example, they don't have the requisite volume of data or the capabilities to manage data or develop necessary analytics. Unfortunately, some cities are finding this out after significant investments are made. Money is being spent, but value creation in such cases is limited (Pardo, 2019).

Strategies for making a city smarter often rest on the use of best practice solutions borrowed from what are generally recognized as the world's smartest cities. Many of these solutions are based on "smart city technologies" and are driving significant investments. The less often told story is that many of these investments do no generate the expected value. These efforts often rely on what Albert Meijer, a leading smart city researcher from the Netherlands calls, "universal patterns." Universal patterns emerged when one city after another successfully adopted highly technical strategies focused on solving very technical problems (Meijer, Gil-Garcia, & Bolivar, 2016). Overtime however, as smart city strategies moved beyond strictly technical innovations to become more socio-technical, and encompassing such things as the delivery of social services, the more it became clear that context matters (Dawes, Cresswell, & Pardo, 2009; Gil-Garcia et al., 2015; Gil-Garcia, Dawes, & Pardo, 2018; Meijer et al., 2015; Pardo, 2019). What is increasingly clear is that mayors and urban policy makers need more nuanced understanding of the issues facing cities and of the range of contextual conditions that influence the success of smart city investments. They must use that new understanding proactively to make decisions that keep cities viable and livable.

As pressures on the world's cities and in particular, city governments, increase due to a wide variety of factors, including population growth and reductions, economic crises, public health crises, climate change and shifting demographics, among others, we are seeing rapid changes in the context of the world's cities. We are seeing more "wicked problems" (Rittel & Webber, 1973; Weber & Khademian, 2008). Wicked problems according to Rittel and Weber have ten characteristics: "(1) Wicked problems are difficult to define. There is no definite formulation. (2) Wicked problems have no stopping rule. (3) Solutions to wicked problems are not true or false, but good or bad. (4) There is no immediate or ultimate test for solutions. (5) All attempts to solutions have effects that may not be reversible or forgettable. (6) These problems have no clear solution, and perhaps not even a set of possible solutions. (7) Every wicked problem is essentially unique. (8) Every wicked problem may be a symptom of another problem. (9) There are multiple explanations for the wicked problem. (10) The planner (policy maker) has no right to be wrong." We are also seeing, according to Dawes et al. (2009) "a broader category of equally challenging but more commonplace 'tangled' problems which lie in a vast middle ground between routine and wicked problems." Peters (2017) adds the general sense after reviewing Rittel and Weber's list that wicked problems involve multiple actors and are socially and politically complex.

According to livability.org,[1] there are five fundamental aspects of great, livable cities: "robust and complete neighborhoods, accessibility and sustainable mobility, a diverse and resilient local economy, vibrant public spaces, and affordability." City leaders around the world are working to identify and close the livability gaps in their cities. Closing those gaps requires a variety of highly interdependent policy, management, and technology innovations, it requires cities to look beyond universal patterns in technical systems and toward social and economic innovation. How successful city leaders are in responding to changing pressures on the livability of their cities relies to a great extent, in our view, on their ability, or in many cases, their willingness, to invest in building an understanding of the specific context of their city. Unfortunately, building nuanced understanding of context rests on willingness to take the time to unpack the complicated ways that the context of a city interacts with the sometimes wicked and often tangled problems that a city is facing, the innovations expected to address those problems, and the capability required to be successful. Taking the time to build that understanding is often at odds with the pressure on city leaders to act quickly (Pardo, 2019).

This chapter presents our argument that making a city smarter rests on the capability of that city to create public value for those who live and work there. Such capability, in our view, is a function of the context. How does context matter in smart cities development? This is the question that needs new attention. According to Merriam Webster, context is "the *interrelated* conditions in which something exists or occurs." In this essay we join fellow scholars who have called for new research about the role and impact of context (Gasco-Hernandez, 2018; Meijer et al., 2016; Pardo, Nam, & Burke, 2011) including in the areas of smart governance (Meijer & Bolivar, 2015), smart city initiatives such as business registration (Gil-Garcia & Aldama-Nalda, 2013), small to medium size cities (Pardo, Canestraro, & Cook, 2014), smart city policies (Caragliu & Chiara F. Del Bo, 2015), and how the policy and democratic context influences the development of smart cities (Meijer, 2017).

Understanding the context of a city requires studying the interrelated conditions of that city. It means creating understanding of the challenges, capabilities, characteristics, and successes of that particular city. It means investing in processes that examine the unique nature of the problems facing a city, the resources that a specific city has to draw on to solve its problems, and what stakeholders in that city see as solutions. It also means finding out why a smart city investment has or has not worked in other cities, and then using insight about how the context, or the interrelated conditions, have impacted the outcome of similar innovation efforts. When investment choices are made by city government officials without a full understanding of what factors cause an innovation to create value in one city and what must happen in their own city for that investment to create similar value, value creation is limited. Our position is that in large part, neither researchers nor practitioners fully understand how context and capability influence the outcome of smart city initiatives

[1] Livable City: https://www.livablecity.org/missiongoals/.

and that context is not currently considered in a sufficient and robust way in smart city investment decision-making. Our goal is to call attention to these gaps, and ideally as a consequence, increase critical consideration of context in smart city investment decisions.

This chapter is organized in four sections including this introduction. Section "Smart Cities, Context, and Public Value Creation" provides a brief overview to the concepts used in presenting our argument and some selected efforts to highlight the need to center context. Section "Smart City Innovation, Context, and Public Value: A Selected Set of Case Studies" presents a selected set of case studies of smart city initiatives that highlight the critical role of context and the efforts of scholars to build sophisticated understanding of context and implications of that context and a set of insights generated from the cases and Section "Building Public Value through Context-Specific Smart Cities Investments Discussion" closes the essay with some recommendations designed to help smart city leaders increase the likelihood of public value creation through smart city investments.

Smart Cities, Context, and Public Value Creation

As backdrop to our argument that making a city smarter rests on the capability of that city, as a function of context, to create public value for those who live and work there, we provide a brief review of the three central concepts of smart cities and context, and draw on a selected set of articles that are emblematic of the increasing recognition among scholars of the critical role context plays in public value creation in smart cities and the need for new understanding of the interplay of context and innovation.

Smart Cities

Smart city first appeared as an "object of scientific inquiry" in 1992 (Mora, Bolici, & Deakin, 2017) within a book entitled *The Technopolis Phenomenon: Smart Cites, Fast Systems, Global Networks* (Gibson, Kozmetsky, & Smilor, 1992). Since that time scholars and practitioners from a range of disciplines and professions have been working to understand what makes a city "smart." They have developed and examined conceptualizations and frameworks (Chourabi et al., 2012; Giffinger et al., 2007; Nam & Pardo, 2011), models and architectures (Kuk & Janssen, 2011), ranking systems (Giffinger & Gudrun, 2010; Intelligent Community Forum, 2020), and strategies and solutions (Estevez, Lopes, & Janowski, 2016).

Giffinger et al. (2007), in an important departure from early works that were primarily technically focused (Mora et al., 2017), provided a foundational contribution to these efforts by conceptualizing a smart city as "a city well-performing in a forward-looking way in various characteristics" (economy, people, governance, mobility, environment, and living), "built on the smart combinations of self-decisive, independent and aware citizens." Building on work from Giffinger et al. (2007), Nam and Pardo (2011) put forward a view of smart city built on the three conceptual dimensions of a smart city, technology, people, and community. Like Giffinger et al. (2007), Nam and Pardo (2011) looked beyond the technical aspects of smart cities and worked to advance the discussion of context, calling a smart city a "contextualized interplay among technology innovation, managerial and organizational innovation, and policy innovation."

A leading framework proposed by Gil-Garcia, Pardo, and Nam (2015) draws on these seminal works and offers a comprehensive view of smart city components and elements (see Fig. 1). Over time and through continued consideration of this framework in different contexts, the framework has been expanded to reflect an evolving view of what makes a city smart. For example, one of the original dimensions of that framework, "environment," was originally envisioned as the city government's ability to manage and monitor environmentally related systems and actions, but today, as a consequence of changing views and new research, this framework now incorporates the extent to which a city is considered environmentally friendly (Gil-Garcia et al., 2015). This framework, and others based on it, now include human capital, creativity, and the knowledge economy, among others, as components of smart cities. More recently, smart governance is receiving attention as well (Meijer et al. 2016). These efforts show that what we understand to be a smart city reflects a dynamic range of social, institutional and organizational as well as technical innovations. As a consequence of these efforts, today's smart city frameworks are

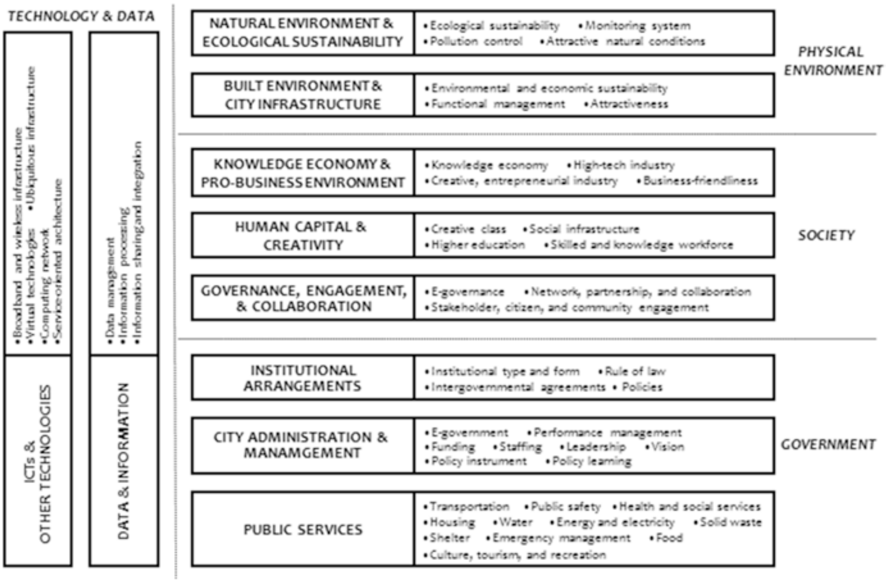

Fig. 1 A comprehensive view of smart city components and elements, Gil-Garcia et al. (2015)

multi-dimensional and integrative. They are reflective of the rapid technical, social, and organizational innovations that have occurred through the years and have benefitted from continued testing and reconsideration within a wider range of contexts. For the purpose of this paper and our argument, we adopt the conceptualization proposed by Gil-Garcia et al. (2015) of a smart city as a "socio-technical" phenomenon (see Fig. 1).

The Critical Role of Context in Smart City Investment Decision-Making

Context matters. This claim seems to be well-supported, rarely challenged and is gaining traction in international, national, and local debates about digital transformation at all levels of government including cities (E-Government Survey, 2020). This claim is particularly resonant with smart city scholars. As Nam and Pardo (2011) note, "the unique context of each city shapes the technological, organizational and policy aspects of that city." Examinations of the interplay between context and innovation allow for the identification of smart city investments and strategies that are uniquely relevant to a particular context, of actions that must be taken within that context to create public value, and an understanding of the unique risks of that particular set of actions within that specific context (Gil-García & Pardo, 2005; Hartley, 2005 and Toppeta, 2010). Over time, as researchers and practitioners have evolved their understanding of what it *means* for a city to be smart more researchers are turning to understanding what it *takes* for a city to be smart.

Leading smart city researchers and practitioners are calling for more emphasis on building understanding of the context of cities as input to smart city decision-making, or as defined by Merriam Webster, "the *interrelated* conditions in which something exists or occurs." Meijer et al. (2016) and Gasco-Hernandez (2018) acknowledge that we don't know enough about how context impacts outcomes (Meijer & Bolivar, 2015). Knowledge of the relationship between context and approaches to making cities smarter is according to Meijer et al. (2016) "underdeveloped" and "lacks the sophistication required to provide guidance to policy makers." Meijer et al. (2016) note that while "many studies highlight the significance of the general context, they do not provide a sufficient and systematic analysis of the phenomenon." Aurigi and Odendaal (2020) call for "revealing and reaffirming" and re-embedding the qualities of place and the human agency that critically contribute to what they call "city making." Foregrounding technology as an alternative, in their view, "makes place and human agency invisible." Studies that present the kind of systematic analysis that generate new understanding, that go beyond our generic or "universal patterns" are necessary if we are to build new understanding of what it takes for a specific city to create public value by being a "smart" city.

Through their analysis of the e-government literature, Castelnovo and Sorrentino (2017) suggest that "above all, the context in which implementation occurs, determine the success or failure of a multi-organizational program." Their review identified three issues they consider to be particularly crucial to success (Castelnovo & Sorrentino, 2017): (1) the design of the coordination arrangements; (2) the distribution of the competences and responsibilities across multiple actors; and (3) the capacity of each council to adopt appropriate change management strategies to translate the ICT resources into capabilities (Rose & Grant, 2010). They conclude that a "multi-layered dynamic context is central to a range of theories that can strengthen our understanding of the determinants of organizational change. In fact, the studies that treat digital government as merely a technical matter, focusing on a single organization, do not capture the role of ICT 'in context' that is essential to gaining realistic insights."

Recent examinations of the current literature have highlighted what is known about two key enablers to smart cities: smart city governance and smart city leadership. These studies provide evidence of shifting patterns toward the more systematic analysis being called for. In 2018, Ruhlandt (2018) built on the efforts of Bolivar and Meijer (2015) by adding "clarity and rigor to the ongoing debate about context, and in particular SCG [smart city governance]". Ruhlandt's comprehensive review of the "defining components of SCG, compiling the various metrics used to measure SCG and the potential influence contextual factors, thereby representing the perspectives on the outcomes of SCG" concluded that few "mention, theorize or examine the potential role of contextual factors in SCG." Among those that do attend to context, Ruhlandt (2018) notes, earlier articles placed emphasis on "degree of autonomy," with later articles also beginning to consider "local conditions."

In their 2020 article, Sancino and Hudson begin to address what they consider a *surprising* gap and a "neglected angle" in empirical analysis and theoretical discussions of leadership in, of, and for smart cities. The perspective they take in their work is "leadership for a purpose in a given context." Sancino and Hudson (2020) draw on what they call "rising" literature on leadership and public and collaborative governance within the public management literatures and place-based leadership from within the urban and regional studies literatures and on emerging literature and within leadership and organizational studies that focus on the impact of leadership in society (see Table 1). Through their work, Sancino and Hudson (2020) identified four "modes" of leadership: smart cities as digital government, smart cities as digital driver for economic growth, smart cities as an open platform for digital sociopolitical innovation, and smart cities as an open platform for digital economy. They note that the four modes of smart city leadership influence the type of action activated in a smart city initiative. They highlight the key role of the local government leadership in making smart cities happen and provide a set of lenses for analysis. For any of the four modes of smart cities leadership, local governments may play different roles, but all roles require them to "act as the pivot of the network of actors that can take a role in implementing smart cities projects."

Table 1 Closing the gap in the neglected angle of smart city leadership

dFocus	Literature	Perspective/Purpose
Leadership and public and collaborative governance	Public Management Beer et al. (2018), Sotarauta, Beer, and Gibney (2017), Acuto (2013); Hambleton (2015), Sotarauta (2016), Sotarauta and Beer (2020), Budd and Sancino (2016), Crosby and Bryson (2018), Hartley (2018), Liddle (2010), Vangen, Hayes, and Cornforth (2015), Van Wart (2013), Tummers and Knies (2013)	A rising literature on the role of leadership in public and collaborative governance which studies leadership across organizations and in the public sphere with a more outward and community-based focus than the longer existing research on administrative and/or organizational leadership in public sector settings
Place-based leadership (also referred to as city and regional leadership)	Urban and Regional Studies Sotarauta et al. (2017)	A rising literature that aims "to understand better how and to what extent the places where we live, work, and play are shaped by human relationships and interactions and, specifically, in what ways the meanings ascribed to concepts such as leader, leading and/or leadership can be used to explain how these places evolve"
The impact of leadership in society	Leadership and Organizational Studies Uhl-Bien, Marion, and McKelvey (2007), Jackson and Parry (2018)	An emerging literature which discusses the impacts of leadership in society, characterized by the fundamental importance of understanding leadership in a complex and changing context and as a practice of leading and following for a purpose

Adapted from Sancino and Hudson (2020)

Smart City Innovation, Context, and Public Value: A Selected Set of Case Studies

A set of recent case studies are selected to provide support for our argument that making a city smarter rests on the capability of that city, as a function of context, to create public value for those who live and work there. These cases model ways to look beyond generic patterns of smart cities toward building new understanding of the capabilities required for a specific city to create public value through a specific smart city initiative. They draw attention not just to the need to recognize the importance of context, but of the need for systematic analysis of how the context, or interrelated conditions, in particular the key role of local government leadership in making smart cities happen, have impacted the outcome of similar smart city innovation efforts called for by Meijer et al. (2015) and others. Table 2 provides a summary of these cases in terms of their conclusions, including specific conclusions about the role of leaders and the implications for context requirements. These cases highlight insights gained about how specific characteristics of an envisioned

Table 2 The interplay between characteristics of an envisioned innovation and context

Author(s)	City Initiative	Conclusions	Implications for Context
Gil-Garcia and Aldama-Nalda (2013) *Data and Information Governance, Engagement and Collaboration Institutional Arrangement City Administration and Management*	Mexico City Services integration	• Inter-organizational collaboration is key to building integrated service networks • Integration of data into a single platform that can be used by different government and non-government actor is key to building integrated service networks • Involvement of the mayor allowed for the creation and improvement of necessary institutions and organizational structures • The lack of a strong civil service in Latin American Local Governments necessitates the support of a political leader for a technological project	• Requires context within which a mayor is willing to exert his or her political power to aligned multiple, sometimes conflicting political interest and to create formal institutions and organization structures as needed • Requires context within which the mayor is willing to exert his or her political power to create "operating rules for diverse programs to harmonize their processes and performance"
Gil-Garcia, Pardo, and DeTuya (2019) *Data and Information Governance, Engagement and Collaboration Institutional Arrangements City Administration and Management*	New York City Information Sharing in Megacities	• Inter-organizational collaboration is key to building integrated service networks • Mayors engender more managerial flexibility leaders to fewer challenges to efforts to modify rules and organizational structures • Financial resources and technical skills, both well-recognized challenges to smart cities in general, were not found to be as important in these cases	• Requires context within which a mayor is willing to exert his or her political power to aligned multiple, sometimes conflicting political interest and to create formal institutions and organization structures as needed • Requires context within which the mayor is willing to exert his or her political power to create "operating rules for diverse programs to harmonize their processes and performance" • Requires context within which an enterprise view of city-wide integration of programs and services is achievable

(continued)

Table 2 (continued)

Author(s)	City Initiative	Conclusions	Implications for Context
Gasco-Hernandez (2018) *Governance, Engagement and Collaboration* *Knowledge Economy and Pro-Business Infrastructure* *City Administration and Management*	Barcelona Smart City Strategy	• Need a smart city strategy to serve as a foundation or framework for a suite of smart city projects • Even before the smart city projects, few projects had required the participation of individuals and groups or communities, so there was a lack of a bottom-up approach • Sustainability of a vision of a political leader requires that the leader's vision and the community's vision are aligned	• Requires context within which a strategic view exists • Requires an investment building a shared vision to guide strategy that is shared beyond the political leaders • Requires context within which government is willing and able to engage citizens as partners • Requires context within which citizens trust government and are willing to engage as partners with government
Berntzen and Johannessen (2015) *Governance, Engagement and Collaboration* *City Administration and Management*	Arendal and Sarpsborg, Norway Citizen participation in the development of smart cities	• A lack of clarity of purpose for participation can result in engagement strategies that are unsuccessful • Ensuring active and productive citizen participation often requires the use multiple modes of engagement • A challenge when implementing citizen participation is how to operationalize the role of citizens in a particular project • Government employees in particular are concerned about having a clear division between their role as facilitator and executor of decisions and the decisions being made by politicians, in order to maintain the division between bureaucracy and elected politicians	• Requires commitment to creating clarity of purpose with respect to "citizen participation" • Requires engagement modes that are fit to purpose • Requires context within which citizen engagement is informed and enabled by understanding of relative roles and responsibilities of citizens and the government • Requires context within which bureaucrats and politicians understand their relative roles as facilitator and executor of decisions

(continued)

Table 2 (continued)

Author(s)	City Initiative	Conclusions	Implications for Context
Tang, Hou, Fay, and Annis (2019) *Governance, Engagement and Collaboration City Administration and Management Public Services*	Tallahassee, Florida, USA DigiTally	• In general, the characteristics of the city appeared to favor the specific smart city investments • Context is complex and multi-layered and a lack of attention to the context complexity can result in counter-intuitive findings • Messaging strategies must reflect deep understanding of the characteristics of communities	• Requires context within which assumptions about local context based on general characteristics are tested • Requires a context in which deep understanding of communities is valued and used to inform strategic investments in smart city initiatives

innovation require a specific context for success. This analysis provides support for three points for policy makers (Sancino & Hudson, 2020), who could see themselves as “leadership for a purpose in a given context”: (1) They must understand the context required for an envisioned innovation to succeed, (2) They must understand the context within which the initiative is being envisioned, and (3) They must take action to close the gap in capability or to revisit their original vision.

Building an Angel Network, Mexico City

In their analysis of the Angel Network in Mexico City, Gil-Garcia and Aldama-Nalda (2013) examine the role of political leadership in information integration. Angel Network is a system that integrates information from all social service programs across city agencies and requires the participation of most city social development agencies. To be successful, a project such as Angel Network requires high levels of collaboration across agency lines, across business processes and data streams and effective organizational and institutional mechanisms to enable such collaboration and integration (Gil-Garcia & Aldama-Nalda, 2013). Unfortunately, according to Gil-Garcia and Aldama-Nalda (2013), Mexico City did not have the capabilities required for success in place. However, what Mexico City did have was a mayor who understood that his actions as leader in exerting political will in support of this project was necessary to align multiple and sometimes conflicting political interests and to create new operating rules designed to harmonize processes. The case study shows that the level of policy, management, and technology innovations required to build and sustain the Angel Network was significant and required a strong political leader, in this case, a mayor had an enterprise view of the implications of the creation of the Angel Network in terms of change and the political will to prioritize and make center on his agenda, the necessary changes. Drawing on the Gil-Garcia et al. (2015) smart city framework, the Angel Network comprises at least four components of smart cities: Data & Information, Governance, Engagement & Collaboration, Institutional Arrangements, and City Administration and Management

Information Sharing in Megacities, New York City, USA

In an effort to build new understanding of the utility of current information sharing research, Gil-Garcia et al. (2019) conducted a case study to determine the extent to which previous findings about information sharing and integration (e.g., Luna-Reyes, Gil-Garcia, & Cruz, 2007; Pardo et al., 2011; Scholl, Kubicek, Cimander, & Klischewski, 2012) held in the context of smart cities, and in particular, smart cities initiatives in “megacities”; metropolitan areas comprised of one or more cities plus their suburbs (United Nations, 2006). They note that megacities, such as New York, are at the forefront of smart cities efforts including the application of information and communication technology as tools to create pubic value through innovative problem-solving capabilities. In particular, they note that a “core” capability for many of these initiatives is information sharing across organizational boundaries (Gil-Garica et al., 2019). The case analysis highlighted a relatively classic set of interorganizational information sharing challenges, including the need for enterprise level changes to organizational and institutional structure and processes, as well as significant technical and data related innovations. But they also generated some novel insights about how leadership in megacities, in particular, in the form of the mayor, played a pivotal role in overcoming these challenges, for example, by exerting political will to center the kinds of changes necessary. But interestingly, they also found that two challenges in particular, financial resources and technical skills, both well-recognized challenges to innovation in general, were not found to be as important in these cases. One observation provided by the authors is that megacities may have some of the advantages found in larger government jurisdictions, such as states in terms of the availability of financial resources and technical skills. This availability of resources combined with a strong local government leader creates opportunity for place-based leadership to create value in cities. Drawing on the Gil-Garcia et al. (2015) smart city framework, NYS’s smart city agenda comprises at least three components of smart cities: ICT & Other Technologies, Data & Information, Institutional Arrangements, and City Administration & Management.

Barcelona, Spain

Barcelona is recognized as among the most advanced smart cities, as a consequence, it is also often considered a model for other cities (Gasco-Hernandez, 2018). Starting in 2011 with a new mayor and following decades of stagnation and unemployment, Barcelona’s city leaders were incentivized to reinvent the economy and social profile of Barcelona. As outlined by Gasco-Hernandez (2018) two strategies were prioritized for the agenda, (1) use new technologies to foster economic growth and (2) improve the well-being of citizens. Close to 20 projects were launched under these priorities. To be successful, Barcelona's smart city agenda rested on the capacity of public organizations and public services to plan, implement, and assess a strategy as well as engage citizens and other stakeholders in its development (Gasco-Hernandez, 2018). From a practical point of view, according to Gasco, this involved developing a city model co-conceptualized and co-implemented with ordinary citizens and other stakeholders. Three factors were found by Gasco-Hernandez (2018) as contributing to challenges to that agenda: (1) the lack of a smart city strategy to serve as a foundation or framework for a suite of smart city projects, (2) no bottom-up approach for engaging citizens, and (3) the lack of a shared vision of Barcelona as a smart city. Barcelona's mayor had a vision, but the vision did not get translated into a framework around which the variety of projects could be organized and linked and around which stakeholders could build support. Little attention was paid to connecting the projects in a superstructure that could be used to engender support. Performance of initiatives was measured in outputs rather than outcomes, and virtually no attention was paid to engaging citizens in efforts to address their well-being and as a consequence little support for that priority within the agenda was built. Barcelona's mayor did not exercise leadership neither in terms of public and collaborative governance nor as a place-based leader. Drawing on the Gil-Garcia et al. (2015) smart city framework, Barcelona's smart city agenda comprises at least three components of smart cities: Governance, Engagement & Collaboration, Knowledge Economy and Pro-Business Infrastructure, and City Administration & Management.

Municipal City Projects, Norway

In their examination of the role of citizen participation in smart city projects, Berntzen and Johannessen (2015) argue that being a "smart city" includes a dimension of "being more attentive to the needs of its citizens" and that participation is the key to achieve better solutions, services, and democratic involvement. Citizen participation in their cases was centered in two projects focused on digital planning and a third focused on the use of social media to increase responsiveness to citizens. While the case analysis conducted by Berntzen and Johannessen (2015) was primarily focused on technologies for citizen engagement, they gained several insights into capability requirements for successful citizen participation in smart city projects. They note a critical first step of clarifying the context and formal placement of input from citizen participation and that this placement is a function of the complexity of the project. They offer three recommendations as input to these clarifying processes and placement decisions: (1) Projects aimed at gathering citizen experience and knowledge should consider a hybrid approach which combines social media and offline activities, (2) Projects aimed at collecting data through citizens' use of smartphones likewise should consider a hybrid approach, and in this case, proprietary systems may be necessary to collect the data and do meaningful analysis, and (3) Projects where participation is seen mostly as a democratic value, technology should include a mix of discussion forums, social media accounts, and offline activities such as town hall meetings (Berntzen & Johannessen, 2015). Leadership in public and collaborative governance and place-based leadership was missing in these cases. Drawing on the Gil-Garcia et al. (2015) smart city framework, the municipal smart city project in Norway comprises at least two components of smart cities: Governance, Engagement & Collaboration, and City Administration & Management.

Tallahassee, Florida, USA

In their study of city management mobile apps for smart governance in the City of Tallahassee, Florida, Tang et al. (2019) work to fill the gap they see in systematic investigations of the drivers and barriers to citizen engagement and co-production through city management apps; such barriers they note, have "not been subject to extensive scholarly investigation." Tang et al. were also incentivized to carry out this study due to their observation that while smart city management apps, such as "311" request platforms including Europe's FixmyStreet or the USA's SeeClickFix, "local governments are not seeing the potential of these city management apps" for "smart governance" (Meijer & Bolivar, 2015). The City of Tallahassee provides a unique context in that it is recognized as a leading digital city with a young, well-educated population and a digitally progressive government (Tang et al., 2019). Tallahassee, according to Tang et al. (2019), is an "extreme case" of a smart city, in a sense an "ideal environment for adopting city management apps for smart governance." The drivers for Tallahassee's "DigiTally" app, according to government officials interviewed for Tang et al.'s study, were improvements in efficiencies of public service delivery, in particular for Tallahassee's elderly population, and in citizen engagement more generally. Classic facilitators for adoption were also identified as in place by those officials, including top management support and internal marketing. However, regardless of Tallahassee's unique context and the presence of facilitators, citizens did not download and use the app as anticipated (Tang et al., 2019). The findings are somewhat counter-intuitive as the barriers to download and use were found to be awareness of the app among citizens and the digital divide. A closer look at Tallahassee through the lenses of this study revealed that citizens with high digital literacy and well-versed in apps were unaware of DigiTally, and of those who were, likely due to their digital literacy, preferred apps with more features and functionality. Further, the closer examination also revealed a digital divide among the elderly, not in terms of financial resources to access mobile devices, but in terms digital literacy and as a consequence, they were not knowledgeable about mobile devices nor "apps" in general, nor DigiTally as a specific mechanism for accessing government services. While marketing had been done, few of those involved in the study got the message. Drawing on the Gil-Garcia et al. (2015) smart city framework, the DigiTally project in Tallahassee comprises at least three components of smart cities: Governance, Engagement & Collaboration, City Administration & Management, and Public Services.

The Value of Systematic Analysis of Context

These cases illustrate how systematic analysis of context, of the interrelated conditions found among policy management and technology innovations can inform smart city decision-making. They also illustrate the key role of leadership and the utility of the emerging work focusing on leadership in smart cities in particular. In the cases of Angel Network, NYC 311, and Barcelona, leadership was key to success. In both Angel Network and NYC 311, the mayor was instrumental to the changes required to be successful. The depth and complexity of the innovations and the sheer number of agencies and other relevant organizations that had to be coordinated required such leadership. The same leadership was required in Barcelona, both leadership in public governance and collaboration and in place-based leadership. Neither of these were forthcoming, and the lack of a leadership to create an organizing framework for the city government and to create an engagement culture were missing. Many things happened in Barcelona but without the leadership necessary to succeed with a city-wide transformation in a city with a history of social and economic problems, actions of the city government were neither coherent nor coordinated, and so, were in the long run not sustainable. The Norway and Tallahassee cases both highlight that sometimes the barriers to smart city initiatives are counterintuitive. They illustrate that a depth of understanding of the particular innovations and the particular context must be created. In both Norway and Tallahassee the city governments acted on what might be considered generic statements of the characteristics of the technology innovation and the communities themselves. Place-based leadership and the practice of leading and following for a purpose was required.

The Gil-Garcia et al. (2015) framework provides another set of lenses through which to systematically unpack the interrelated context within which smart city initiatives will or are taking place. Across the five cases the smart city projects mapped primarily to six components of smart cities: Data & Information, Governance, Engagement & Collaboration, City Administration & Management, Institutional Arrangements, Knowledge Economy and Pro-Business Infrastructure, and Public Services. These components, except for Knowledge Economy and Pro-Business Infrastructure center the role of government and of local government leadership. They center the need to understand when and how to engage with citizens, when and how to provide public services and what policy, management, and technology innovations are required for value to be created through those innovations. As urban policy makers begin to recognize the need for deep understanding of context and use of that understanding in smart city investment decision-making, this framework might serve as a guide to the kinds of capability required to make specific kinds of changes and to make assessments about the extent of and the relevance of existing capability.

Building Public Value through Context-Specific Smart Cities Investments Discussion

Our goal in presenting this essay is to increase the likelihood that important decisions about the future of the world's cities are made with critical consideration of context. For academics and researchers, we call for new research that focuses on the role of context in smart city investment decision-making. We believe in doing so communities will increase the likelihood that their smart city investments will create sustainable public value. For smart city leaders we call for a new focus on context-specific approaches to decision-making about smart city investments that reflects a deep understanding of the complexities and interconnections among social and technical factors of services and physical environments in a city, when making investment decisions (Nam & Pardo, 2011).

We seek to incentivize mayors and urban policy makers to build an understanding of the context of their cities and of the cities they look to for best practices. If they find a strategy in another city that they believe will help make their city smarter, they must ask hard questions of those cities; they must understand the interrelated conditions in which that success occurred. They must look to the work of Sancino & Hudson (2020) and others, for models that help them "understand better how and to what extent the places where we live, work, and play are shaped by human relationships and interactions and, specifically, in what ways the meanings ascribed to concepts such as leader, leading and/or leadership can be used to explain how these places evolve." They must answer difficult questions about whether their cities have the conditions necessary to become more livable. They must know if they have the resources local government leaders need to close the livability gaps in their cities, if they must adapt the innovation to their context, or if they will have to continue to look for new ideas. In this essay, we've illustrated the need for urban policy makers to look internally to see what problems matter more and make decisions that are locally relevant and context specific. To make a city smarter, to create value for those who live and work there, urban policy makers must understand the relationships among the context of the city, the characteristics of the problems in that city, and the characteristics of the innovations that are being considered as solutions to those problems. As leaders, they must both drive efforts to create that understanding and to use it to inform smart city investment decisions. To put nuanced understanding of context at the center of smart city investment decisions, urban policy makers must (Pardo, 2019):

1. Look globally for inspiration; but look locally to see what matters most to the people in your city.
2. Look globally to see what is doable; but look locally to see what's reasonable in your city.
3. Look locally to understand the source of and nature of pressures on your city. What is the context of your city and how is it impacting and interacting with the pressures on your city?

4. Build partnerships with smart cities researchers to help build an understanding of the impact of context and how to understand your local context better.
5. Look globally to see how the world's leading cities are responding to new pressures from urbanization and de-urbanization, but look closely at what makes those smart city innovations possible in that place and at that time. Ask yourself, will that work here? If not, what must you change to make it work in your city? Is it feasible? Finally, you must decide, is it worth it?

As the world around us changes and those changes create new and complex problems, urban policy makers must recognize the need for a deeper understanding of the specific context of cities and resist the temptation to fast track by defaulting to generic, universal patterns of innovation. Smart city leaders seeking to make their cities smarter through policy, management, and technology innovation must work in partnership with researchers and practitioners to shed new light on how and in what ways context influences public value for their cities and those who live and work there. These leaders must learn how a lack of attention to context is making it difficult for their cities and their partners to respond quickly and effectively to the increasing challenges caused by the dynamic nature of the demographic, social, economic environmental and political conditions of today's cities and communities. The cost of not learning these lessons is that investments in innovations of all kinds are being made even when the context necessary for value to be created through those investments is missing.

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The Green Dimension in 11 Smart City Plans: Is There an Environmental Ethic Embedded in Long Term Strategic Commitments?

Olga Gil

Abstract We analyze and compare 11 city cases in three continents to find out differences and commonalities in the green dimension in smart city plans globally: Shanghai (China), four cities in Japan, Iskandar (Malaysia), New York (United States), and Amsterdam, Málaga, Santander, Tarragona (Europe). The aims of the work has been to test whether there is an environmental ethic embedded in long-term strategic commitments in these local contexts, how different environmental values are, and what lines of research might be interesting to tackle from scientific perspectives in future works where the green dimension is addressed in smart city plans. We find that plan design is very different in the search of a model of a smart city in the 11 cases studied. As we expect choices in plan design to have a long-term impact in terms of environmental outcomes and further resilience, both locally and globally, the environmental ethics attached to the local plans, or the lack thereof, we argue have a strong impact.

Keywords Smart cities · Greening · Sustainable cities · Environment · Urban planning · Comparative public policies

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The funding to collect the data for this work was supported by the Colegio Oficial de Ingenieros de Telecomunicación (COIT), and a report was written then with the comparative results. The idea to focus on the green dimension in smart city plans and build this comparison is novel, and the assemblage of the data for the purpose of this article written in 2019–2020 did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The author thanks the anonymous reviewers of this chapter for their very valuable comments.

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_7

Introduction

As Bakker and Ritts (2018) contend, we already have tools to exert significant changes in environmental governance thanks to the data available through Smart Earth technologies. Bakker and Ritts's very interesting work has propelled us to ask first of all whether there is a green dimension in the smart city plans being carried out by city governments globally. A second question is to what extent and how different this green dimension is treated in smart city plans. We are interested in understanding these differences, from theoretical and practical approaches, and we are eventually interested in contributing to the debate that tackles the ethics of sustainable local environments and in relation with technological development. Through the following sections, definitions of smart cities are introduced along with the hypothesis to be tested, followed by the model of analysis. Later on, the smart city cases are analyzed using a qualitative and comparative perspective. Conclusions, based on both quantitative and qualitative results are provided. The research finds an ethical gap in smart city plans which mostly avoid environmental issues, placing a main focus on technology. This lack of focus on long-term environmental issues at a strategic level is quite evident in the comparison of all these plans, active in 2013–2014. Here we present the results of the research showing the wide differences among measures taken, and the small focus in long-term public policies addressing smart goals in environmental grounds in the first smart city plans drafted for cities. The wide space available to plan policies addressing environmental issues from the perspective of smart city plans is also shown.

Toward a Definition of Smart Cities and the Hypothesis to Test

Drawing upon the literature studying smart cities in the last two decades, we found two traditions and a first set of differences in the definitions of smart cities. Differences in definitions in applied local contexts are important because these are translated into differences in governance locally, as we have later found. Theoretically we found differences among two main approaches to defining smart cities. The first approach focuses on human capital. The second approach focuses on technological progress.

Human Capital

From an economic and growth perspective, a seminal article by Shapiro (2006) draws the link among quality of life, productivity and the growth effects of human capital as main components of the smart cities definition. Winters (2011), in his study on "Why are smart cities growing? Who moves and who stays" in the US, considers a smart city as a "metropolitan area with a large share of the adult population with a college degree, often small and mid-sized metropolitan spaces containing flagship state universities." In the European tradition we find the idea of inclusiveness and regeneration linked to the smart cities concept. Digitally inclusive and regeneration are at the core of Deakin and Allwinkle's (2007) work defining smart cities as those having an e-learning platform, knowledge management and library with the org-ware communities need to support digital inclusive regeneration projects across Europe, meeting advanced visualization, simulation, and benchmarking requirements. For Hollands' work (2008), the social capital is critical to embed the informational and communicative qualities of smart cities. Hollands is linked to an academic tradition that purposely avoids defining intelligence in terms of the world of devices. Such a definition would constraint the smart concept to the artificial intelligence available (Komninos, 2009), and would neglect two other forms of intelligence: human and collective, from the collective skills of population to the social institutions articulating cooperation. Allwinkle and Cruickshank (2011) highlight from Hollands' definitions the emphasis on people and their interactions. In this view, the most important thing about information technology is not its capacity to create smart cities, but the possibility it offers to empower and educate citizens, allowing them to become members of a society that engages in a debate about their environment and social aspirations. It this view, how citizens interact is key to any successful community, enterprise, or venture.

In all contexts, following Deakin and Al Waer (2011), the smartest places combine the best of both the physical and virtual worlds, where presence and telepresence are fused together in a specific location. Physical locations would be pervasively penetrated by digital technologies to provide a collaborative meshing of physical and virtual environments. And this is so because:

> irrespective of how digital technologies are developed to exploit the electronic opportunities they offer, the physical places of urban spaces will retain their relevance in society because people still care about meeting face-to-face and gravitate to places which offer particular cultural, urban, scenic or climatic spaces, unable to be experienced at the end of a wire and through a computer screen (Deakin & Al Waer, 2011).

In Europe, Caragliu, Del Bo, and Nijkamp (2011) argue that a smart landscape is linked to the presence of a creative class, the quality and attention paid to the urban environment, the level of education, and the accessibility to and use of information and communications technologies for public administration. They further show the positive correlation of these variables with urban wealth. Caragliu et al. (2011) argue that those aspects should be part of the formulation of a new strategic agenda for European cities to achieve sustainable urban development and a better urban landscape. Komninos (2009) also brings in knowledge, creativity and social capital as baselines for the definition of intelligent cities. In the tradition of Florida (2002, 2005): the generation of prosperity would depend of the creative class, knowledge workers, scientists, artist, engineers, lawyers, entrepreneurs, and innovators. They are the producers of new ideas, theories, products, and strategies.

According to Komninos (2009, p. 352) three layers are needed in an intelligent environment: (1) the physical space, with the agglomeration of people, innovative clusters and companies, (2) the institutional innovation mechanisms and policies needed for technology transfer, product development and innovation, and (3) the collaborative spaces and tools allowing for people collaboration and participation. Shen, Ochoa, Shah, and Zhang (2011), from a different perspective, but also connected to a sustainable dimension, conducted work doing a comparison of urban sustainability indicators. Shen et al. (2011) used the International Urban Sustainability Indicators List (IUSIL). IUSIL contains 115 indicators, formed into 37 categories, where indicators are structured within four sustainable development dimensions including environmental, economic, social, and governance aspects.

Technology

In the literature one can find scholars from various disciplinary areas, from e-government to information science, urban studies and public administration, and from many different geographic backgrounds (Nam & Pardo, 2011). Within this stream of research, Chourabi, Nam, Walker, et al. (2012) identifies eight critical factors in smart city initiatives that we find interesting to analyze and evaluate to understand innovations in smart city plans: management and organization, technology, governance, as a different variable in Chourabi's approach, policy context, people and communities, economy, built infrastructure, and natural environment. Chourabi et al. (2012) is a very useful integrative framework to examine how local governments are envisioning and pursuing smart city initiatives. This same framework devised by Chourabi et al. allows a focus on the environmental variable and a way to evaluate this variable in smart city initiatives.

In the two theoretical traditions, the environment is a relevant variable. Caragliu et al. (2011) defend a strategic agenda for sustainable urban development as a main part of the smart city concept. Chourabi et al. (2012) also make the natural environment a critical factor in their model. From these two perspectives we could infer the following hypothesis: that the natural environment should be a key focus in smart city plans unveiled by local governments. From this hypothesis we formulated the following questions that we may answer in each of the case studies: Is it really the case that the natural environment is a focus of the smart city plan? If so, to what extent? And, what have been the differences, if any, in smart city plans with regard to strategy and the green dimension associated with long-term goals?

Our choice of cases is driven by an interest to learn from innovative practices in different global institutional settings. It is also driven by the fact that innovation in Asia has been growing at very high rates previously to the period of study. From 2000 to 2005 the growth rate in research and development in China rose by 17% while figures for North America where 5.2% and Europe 3.8% (Komninos, 2009). Moreover, since 2015 the world has changed dramatically, with life becoming more difficult and challenging for the west, yet across Asia these are hopeful times, with rising wealth opening its scale (Frankopan, 2018, p. 10). Isolation and

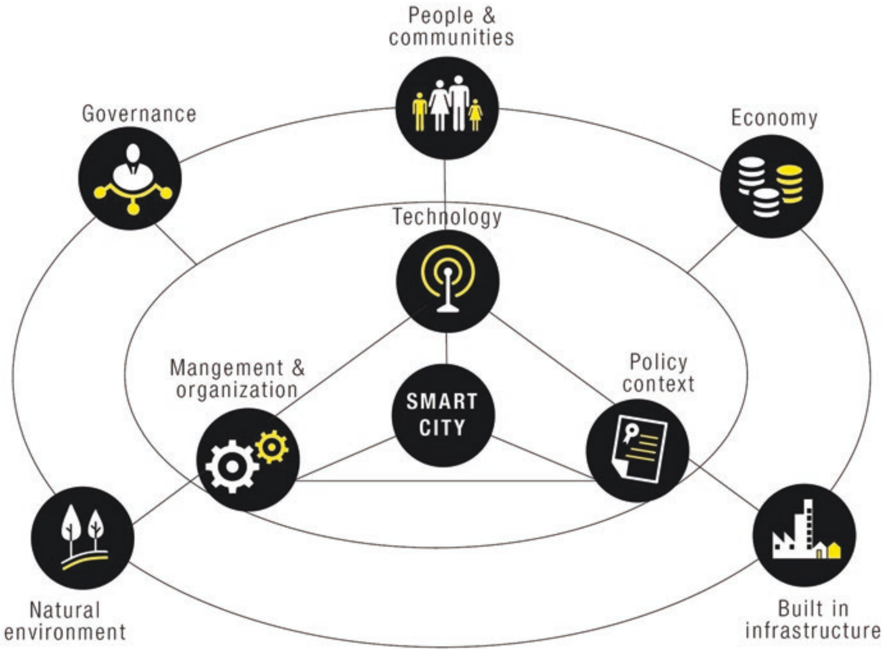


Fig. 1 Smart cities initiatives framework: a visualization developed from the model by Chourabi et al. (2012) and our empirical research

fragmentation in the west stands in sharp contrast with what has happened in the Silk Roads since 2015 (Frankopan, 2018, p. 52), with the shift of global GDP from the developed economies to the east, and China's emphasis on the mutual benefits of platforms for long-term cooperation and collaboration. Thus, we decided against a research design based on the most similar and most different cases. Instead, the decision was to explore first plans of smart cities in Asia, and later on exploring New York and cases within the European context. Thus, we explore cases in Shanghai, China, four cities in Japan, Malaysia (Iskandar), the United States (New York), and the European Union (Amsterdam, Málaga, Santander, and Tarragona—these last three in Spain). We are interested in variations in the selected set of cases. In particular, to what extent and how the natural environment is a focus in each smart city plan. We follow Chourabi et al. (2012) in Fig. 1 and we focus on natural environment public policies in the selected smart city plans.

Research Design and Case Studies

The unit of observation is the smart city plan and the initiatives outlined in each plan. In the selection of cases in terms of, cities and initiatives, we have followed a purposive approach because we are interested in doing logical deductions from different

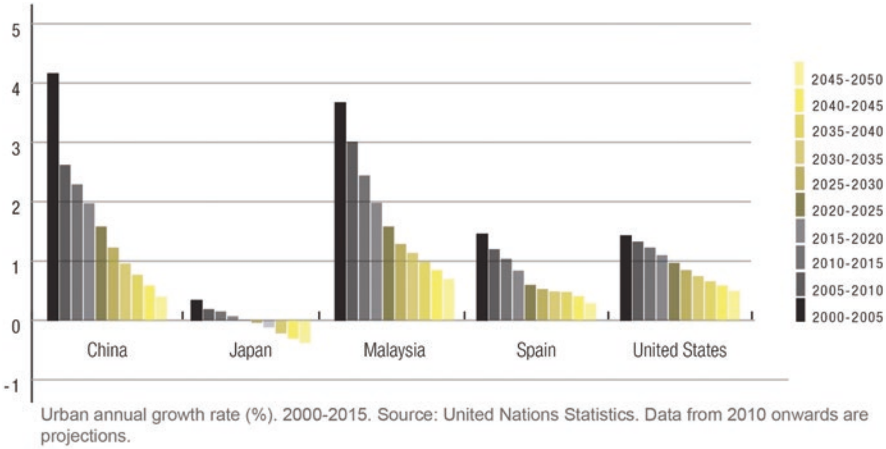


Fig. 2 Urban annual growth rate (%). 2000–2015. (Source: United Nations Statistics. Data from 2010 onwards are projections)

world settings. Following Komninos, "the challenge today is … to gather and integrate knowledge from every available source all over the world (and) for global open systems of innovation (Komninos, 2009, p. 352)" In this empirical study we go on making suggestions for directions and agendas useful for smart city planners, policies and implications for both policy makers and professionals, as well as committed associations with the environment in civil society. For this research we have relied on primary materials, government documents, as reported in the References section, and secondary sources, academic articles, and articles from the press.

The following sections present the empirical analysis of our cases: Shanghai in China, Iskandar in Malaysia, Japanese cases -Yokohama, Toyota City, Keihanna and Kitakyushu-, and New York in the United States, followed by a set of European case studies. Cities diverge widely in terms of demographics, economy, location, population growth, and levels of urban development, among other dimensions. Some differences are reflected in urban annual growth rates, as shown in Fig. 2, and in the initiatives untaken in those cities.

The Green Dimension in the Smart City Plan for Shanghai

We use our hypothesis, that the natural environment is a key focus in the first smart city plan, to analyze the green dimension in the smart city plan of Shanghai in China. The municipality of Shanghai (24 million inhabitants) put in place a 3-year action plan in 2011 to build a smart city (Gil & Zheng, 2017). The idea behind the plan has been to attain an "innovation driven transformation." The plan insists on the guiding principle of socialism with Chinese characteristics guided by Deng Xiaoping Theory. The defined aim has been to become an international economic, financial, trade, and shipping center as well as a socialist modern international metropolis (Lin, 2002). In practice, the plan built on measures taken in the decade of 1990, when informatization was the basis of modernization in three consecutive 5 year plan periods. The tools to make the vision possible draw on:

> Improving the Internet broadband and intelligent application level, build an information infrastructure system of international level, a convenient and highly effective information sensing and intelligent application system, an innovative new generation of IT industry system and a credible and reliable regional information security protection system. [Giving] full play to market mechanism and enterprises, attach importance to government guidance, improve market supervision, vigorously promote the building of future-oriented Smart City carrying mainly digital, network and intelligent features … to raise the city's all-round modernization level and let the citizens share the benefits offered by [a] Smart City.

The natural environment in the smart city plan for Shanghai is related to the energy dimension, and it is concerned with the setup of a smart grid to transport energy to coastal cities in the east coast. Technology and energy are keys to smart developments in China (Liu & Peng, 2013). China has been the most active investor in infrastructure that incorporates intelligence into networks, making them smart in a technological sense—the so-called smart grids. China is focusing on building a smart grid capable of generating and transporting energy from remote inland areas to populated areas on the coast (Gil & Zheng, 2017). This project aims to tackle the challenge of an expected increase in electricity consumption reaching increases of 8.5% per year. China interest on smart grids focuses on technical aspects such as the transmission, standards, integration of renewable energy and electric vehicles, and the implementation of systems that support bidirectional power flows. Challenges include basic questions such as standard network sockets, since there are three different types within the country. With respect to energy, the Shanghai includes a grid-based management system. The city seeks to make applied demonstrations of the smart grid: "building Shanghai into a Smart Grid demonstration city." The original 3-year-plan has contemplated conducting statistics evaluation: Establishing a complete statistical system and social evaluation system to building up the smart city, to strength the capacities of professional institutions by regularly conducting tracking and analysis and releasing the evaluation results. It has contemplated establishing a follow-up and assessment mechanisms for the coordination and implementation of the 3-year Action Plan, incorporating it into the annual performance appraisal system of the relevant departments and districts and county.

From the case analysis of Shanghai, the natural environment is not focal in the first smart city plan in Shanghai. Instead, it appears that growth and the energy needed to support it are focal.

Iskandar, Malaysia

We use our hypothesis, that the natural environment is a key focus in the first smart city plan, to analyze the green dimension in the smart city plan of Iskandar, in Malaysia. The development of Iskandar goes hand in hand with increased linkages within Asia-Pacific countries by air and sea hubs (Ho et al., 2013, Hang, 2011). The government of Malaysia has wanted to strengthen a competitive edge for this Asian region, and thus, it created an Iskandar development region plan in 2006 (Bhaskaran, 2009). The Iskandar Regional Development Authority was later appointed to advance the so-called "new smart goals." Instead of a green dimension as such, in Iskandar the plan leverages on built infrastructure, focused on new residential and business developments as well as educational and recreational areas. For built infrastructure, Iskandar Regional Development Authority reports do not include clear strategies of master planning where the natural environment is focal. According to Iskandar Regional Development Authority reports, these are the pillars of smart Iskandar: (1) Incentives for developers and investors for using green technology and infrastructure; (2) The introduction of a green economy and carbon credits; (3) A public transit system rather than more roads to improve easier movement.

The draft of Iskandar Regional Development Authority for the smart city includes active policies for the natural environment addressing sustainability and reflecting the fact that urban managers acknowledge the challenge of climate change and rapid urbanization for Malaysia. Iskandar Malaysia is currently experiencing population growth rate of 4% and an economic growth rate of 6–8%, and will continue to grow until 2025. With the option of population reduction difficult and remote, planning for a low carbon region would entail reducing CO_2 emission by reducing three main variables: the per capita activity, energy intensity, and carbon intensity of the region (Siong Ho, Matsuoka, Simson, & Gomi, 2013). Policy measures for the reduction of per capita activity could be designed to include (1) promoting low carbon lifestyle and consumption through behavioral change of the increasingly affluent population-including energy saving awareness program and promotion of policies of reuse and recycling campaigns (2) changing building and planning code toward low energy building. However, Siong Ho et al. (2013) notice that these measures have not been adopted in practice. Siong Ho et al. (2013) propose instead, policy actions at a national level to reduce the use of fossil fuel, provide tax incentives to increase use of renewable resources, to use biofuel, hybrid vehicles and buses and use of renewable sources of power in urban areas. These forward looking policies to reduce CO_2 emissions, however, have not been contemplated in Iskandar, Malaysia for the period of study focusing on the first smart city plan.

In the case analysis of Iskandar, we find measures included in the published draft, but there is also a lack of data on how and to what extent the drafted measures have been implemented or turned into policies. The natural environment is not focal in the first smart city plan in Iskandar, however, it comes, in principle, as an acknowledged point to address in the form of changes to building and planning codes toward low energy building.

The Green Dimension in Smart City Plans in Cities in Japan

We use our hypothesis, that the natural environment is a key focus in the first smart city plan, to analyze the green dimension in the first four smart city plans in Japan for the period 2012–2014. The smart city plans in Japan during this period were drafted at the national level (Gil & Navarro, 2013). We selected the first four city pilot projects: (1) The Yokohama project, embarked on a demand response deployment on six large commercial buildings to test the effects of drawing power from storage batteries and energy efficiency measures; (2) Toyota City examines power demand increases as multiple electric vehicles are charged, the use of battery storage and an energy management system; (3) The Keihanna project, that evaluates the use of parked electric vehicles as storage batteries, combined with other recycled storage batteries to reduce power demand from factories; (4) Kitakyushu project, that conducts a dynamic pricing trial with residents as part of its smart communities creation Project, setting incentives to lower consumption and to share data with power firms. The Japanese government acknowledges that social infrastructures, involving electricity, energy, water, buildings, transportation, communications, administrative services, and other elements, are "indispensable factors for ensuring that the lifestyles of the people and businesses can be supported." In order to have all of these established within short periods of time and in a way that makes them useful in the future, the national government set up the master plan for smart cities. The time period for the pilot projects contemplate operational experiments conducted for a 5-year period from 2010 to 2014 in four cities. Projects search ways to make power use visible, to control home electronic devices, hot water systems, demand response, which involves the adjustment of energy demand that is encouraged from the supply side, the linking of electric vehicles and homes, the optimal design of energy storage systems, electric vehicles charging systems, and transport systems. The smart city projects developed in Japan focused on the construction of a next-generation energy society:

> *For resource-poor Japan, the large-scale introduction of renewable energies such as solar and wind power is absolutely essential to the nation's energy security and the reduction of CO_2emissions. The importance of these measures only increased in the wake of the Great East Japan Earthquake of March 11, 2011. However, in order to introduce these renewable energies on a large scale, we must also increase the efficiency of power use and balance supply and demand, and establish a smart grid as a power transmission and distribution network able to stably supply power (Japan Smart* City Portal. http://jscp.nepc.or.jp/en/, http://nepc.or.jp/).

The smart grid and smart cities are considered related to each other in the Japanese model:

> *If we are to utilize energy more efficiently than we have to date, we must not focus exclusively on the power system, but also reexamine our lifestyles looking towards, for example, the use of heat energy and transport systems. This means that it is essential for us to study the feasibility of new social systems, i.e. the ideal form of smart cities. If we take into consideration electric vehicles, the use of which is expected to expand in future, then the way we use energy will also change significantly, for example, electric vehicles batteries will be charged in ordinary households (Japan Smart City Portal.*http://jscp.nepc.or.jp/en/, http://nepc.or.jp/).

The natural environment is a key focus of smart city projects in Japan. Urbanization is a significant issue for Japan, with agricultural land being converted into urbanized areas at the same pace as the rapid growth of developing nations (JSCP, 2014). The focus on the natural environment in smart city projects in Japan has to do with the aftermath of the Great East Japan Earthquake that struck on March 11, 2011, and the subsequent nuclear power plant accident of Fukushima (JSCP, 2014; McLellan, Zhang, Utama, et al., 2013). The smart city projects in Japan mix decentralization of tasks and responsibilities to local and regional governments and include experimentation with modes of non-hierarchical coordination among public agencies and companies. The evaluation of implementation is embedded in the smart city projects, and it is centralized and assessed periodically. Sub-projects carried out within the selected cities are later supervised by the Community Energy Management System (CEMS), in charge of verification and evaluation.

From the case analysis of Japan, we find smart city plans linked to the environment in the particular dimension of energy and the transition from nuclear to electricity power (McLellan et al., 2013). We also find a focus on studies to understand how the population could adhere to a green transition thus defined. For these two reasons, in the case of Japan the hypothesis is proved: the natural environment is a key focus in the first smart city plans, affecting four big conurbations of cities, with the following epicenters built around the Yokohama, Toyota, Keihanna, and Kitakyushu projects.

The Green Dimension in the First Smart City Plan in New York

We use our hypothesis, that the natural environment is a key focus in the first smart city plan, to analyze the green dimension in the smart city plans of NYC developed for the period 2010–2014**.** The evidence links us to the work developed by Dr. Steven E. Koonin, former Under-Secretary for Science in the Department of Energy in the Obama Administration heading the research agenda in New York University's (NYU) Center for Urban Science and Progress. Koonin, with a background as a theoretical physicist and science policy expert, heads the research carried out and linked to NYC's smart city program. The second smart project was developed at the city hall, and focused on smart data (Lohr, 2013, Howard, 2011). As regard to green dimensions, natural environment in public policy has been part of joint programs of the city council with NYU regarding the consumption of water, electricity and computer simulations, such as climate models for weather prediction. However, the focus has been mainly on data. There are no projects that tackle environmental issues from a smart perspective. For former New York Mayor Michael R. Bloomberg, data was set at the forefront to guide operations in city hall. In 2010, the city set up a team of data scientists for special projects in the Mayor's office. The city government committed to giving NYU access to all its public data. That is a rich asset, not only for research, but also for its potential to change government operations and public behavior. Smart plans were adopted by universities such as NYU, investing in urban studies and development with the recently created Urban Informatics School in Brooklyn in spring 2013, with industry partners including IBM, Microsoft, Xerox, Cisco, Consolidated Edison, Lutron, National Grid, Siemens, AECOM, Arup, and IDEO. Institutional partners included nearly 20 offices at various governmental levels, including the Office of Long-Term Planning and Sustainability (OLTPS), The Port Authority of New York & New Jersey, Department of Parks & Recreation (DPR), and the Department of Transportation (DOT). Policies have focused on efficiency. For example, the city council reports that when tapping into data it is possible to streamline building inspections, increasing the efficiency of finding risky conditions in 70% of the inspections. Efficiency is also the axis of partnership with IBM from 2009 launching the IBM Business Analytics Solution Center to address "the growing demand for the complex capabilities needed to build smarter cities and help clients optimize all manner of business processes and business decisions." IBM projects help the city prevent fires and protect first responders as well as identify questionable tax refund claims—a move that is expected to save the city about $100 million over a 5-year period.

From the evidence collected in the case of New York, we find data as the main focus of the smart city plan, and a limited focus on the environment, except for weather prediction. Thus, the hypothesis that natural environment is a key focus in the smart city plan in NYC is not confirmed by the case analysis, except for the focus on weather predictions.

The Green Dimension in Smart City Plans: The Case of Amsterdam

We use our hypothesis, that the natural environment is a key focus in the first smart city plan, to analyze the green dimension in the smart city plan of Amsterdam, Holland. In Amsterdam, the local municipality initiative links the concept of smart with a change in the *energy model and with energy open connectivity*, and through it, aiming to become one of the world's most sustainable cities by 2040 (Peck, 2012, Mak, 2010, Scott, 2009). To achieve this goal, a partnership called Amsterdam Smart City (ASC) among businesses, authorities, research institutions and the citizens of Amsterdam was established. Since its inception in 2009, Amsterdam Smart City Partnership has grown into a broad platform, with more than 70 partners involved in a variety of projects focusing on energy transition and open connectivity. This bottom-up approach to sustainability encourages, in particular, the active involvement of citizens to test-drive new technologies. The municipality's ultimate goal is that these smart, sustainable projects reduce carbon dioxide emissions in line with the targets set at European, national and city levels. However, this aim is today more difficult, considering that the nuclear power moratorium in Germany after the accident at Fukushima in Japan is bringing carbon back in the neighboor country. Nuclear power accounted for 22.4% of national electricity supply in 2010 in Germany, dropping to 17.7% in 2011 and the still growing difference is covered mainly with energy coming from carbon.

Onze Energie, Our Energy in English, one of Amsterdam Smart City Partnership's largest projects, was designed to supply 8000 households with renewable energy, mostly through windmills. The introduction of twenty-first century technology in historical buildings from the seventeenth century of Amsterdam, is expected to reduce CO_2 these households emissions by 50%. By using innovative decentralized generation technology, Ceramic Fuel Cells, the aim is to generate electricity on site. After 20 years of research and development in Australia, cell manufacturer Ceramic Fuel Cells Limited developed a higher powerful cell yield than the modern gas-fired power plant. The CO_2 emissions might be reduced by 50%.[1] Fuel cell technology is very diverse with the experience of many disciplines, from chemistry to materials science to engineering and thermodynamics. Because fuel cells are highly efficient and in the use the fuel is not processed by combustion, fuel cells do not emit large amounts of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (NO_x). The only emission of fuel cells is in the form of water steam, and low levels of carbon dioxide. Companies such as Coolendeavour, Eneco, Gasterra Liander find Ceramic Fuel Cells a promising technology and have decided to introduce a 2 kW fuel cell CFCL jointly a Proof of Concept in the center of Amsterdam: not in a laboratory, but in a 'living lab' environment. With this living test, the so-called Green Bay buildings are fully equipped with self-generated electricity. In this model, electricity is generated at the place of consumption and transmission losses are just about 5%. The total return achieved on energy grounds amounts to 85%.

Since 2012, Amsterdam's Department for Infrastructure, Traffic and Transportation (DIVV) has tried to contribute to resolving traffic congestion by making available to the public all its data on traffic and transportation. Information about parking availability, taxi stands, cycle paths, and live traffic updates are available for all main roads across the city. The data provided has allowed developers and entrepreneurs to create apps to improve the flow of people across the Dutch capital, giving Amsterdammers the chance to make decisions based upon facts and figures, given the city another way to make the city more eco-friendly. Projects include 300 power hookups to recharge electric cars, solar panels on Amsterdam's historic seventeenth century townhouses, and infrastructure upgrades that allow households to sell the energy they generate, from small-scale wind turbines or solar panels, back to the city's electricity grid for a profit. From the evidence collected in the case of Amsterdam, we find policies with a strong environmental focus with regards to energy production and distribution, including empowering citizens and residents to be self-sufficient and to contribute to the public electricity network. In this particular case, we find evidence that the hypothesis is confirmed: the natural environment is a key focus in the smart city plan in Amsterdam.

[1] See: https://amsterdamsmartcity.com/projects/fuel-cell-technology#about. Retrieved on Feb, 21rst, 2020.

The Green Dimension in Smart City Plans: Case of Málaga

We use our hypothesis, that the natural environment is a key focus in the first smart city plan, to analyze the green dimension in the smart city plan of Malaga, Spain. The Malaga Smart City project aimed to be a "remarkable" European initiative for eco-efficient city. Does the city government have grounds to claim so? On-going projects on natural environment in Malaga include the following: (1) V2G technology research (vehicle to grid) aims to develop a delivery system of electric vehicle batteries to the grid, and subsequent analysis of the technical and economic feasibility of the solution; (2) PLC communications between processing centers; (3) Energy efficiency in public and private buildings. Possible energy management of Hospitals; (4) Sensors for noise, pollution, surveillance, communications; (5) Battery management and storage facility in the generators; (6) There has also been an agreement with the building firm Ferrovial, focused on efficient energy management in buildings. Málaga's objectives on eco-efficiency include: increase energy efficiency, reduce CO_2 emissions, and increase the use of renewable energies. A consortium of 11 companies led by Endesa, is deploying, in the Malaga area, technologies for smart metering, network automation, distributed generation and storage, and smart charging infrastructure vehicles.

The goal is better management of energy networks, efficient demand balances and the involvement of all actors in the power system, from generation to consumption. However, compared to the pilot developed in Amsterdam, houses and firms may not become producers rewarded for the energy produced within their own facilities. This is in part due to the fact that national regulations have prevented, measuring and charging citizens for the energy they might produce either at home or at work. Thus, even though the project aims to meet the European guidelines for the energy sector that drives efficiency, use of renewable energy and advanced network storage capacity, the impact is limited for citizens defining their own consumption models. Reduction of CO_2 emissions, automated meter reading, visualization of data online, and the reception of notifications in case of network disconnection are new services, focused on efficiency.

From the evidence collected in the case of Malaga, we find a lack of data showing a focus on the environment in the smart city plan. Thus, the hypothesis that natural environment is a key focus in the smart city plan in Malaga is not confirmed.

The Green Dimension in the Smart City Plan of Santander

We use our hypothesis, that the natural environment is a key focus in the first smart city plan, to analyze the green dimension in the smart city plan of Santander, Spain. Smart Santander started as a 36 month project in September 2010 under EC (European Commission), call FP7-ICT-2009-5. This smart city project was conceived as a pilot project; sensors would be installed in an area of six square kilometers—or 2.3 square miles: The project includes the deployment of 20,000 sensors in partner cities that include Belgrade, Guildford, Lübeck as well as Santander with up to 12,000 sensors, using a “large variety of technologies.” The projects include the following natural environment concerns: The lamps adjust their brightness as needed, dimming when there is no one on the street, and emitting less light during a full moon than on a rainy night. Environmental concerns are addressed in this way. In the Parque de las Llamas, sensors also optimize the amount of watering, so that no water is wasted. Garbage collectors might eventually be able to avoid making unneeded trips, because sensors will inform beforehand which garbage containers need emptying. From the natural environment point of view, smart city policies are driven in the context of economic crisis, and the extent to which pilots might become widely available will very much depend on efficiency as well as to the response to the needs of citizens.

Even though technology is used to provide new smart city functionalities in the city in Santander, from the data collected it is evident the lack of the natural environment as focus in the first smart city plan. Thus, the hypothesis: that the natural environment is a key focus in the first smart city plan of Santander is not supported by the case analysis.

The Green Dimension in the Smart City Plan of Tarragona, Spain

We use our hypothesis, that the natural environment is a key focus in the first smart city plan, to analyze the green dimension in the smart city plan of Tarragona, Spain. The projects drafted for Tarragona’s smart city plan included the following natural environment concerns: (1) Thermal isolation pilot in school with BASF technology, Termabead, to measure the resulting energy savings, (2) Environmental impact of public transportation, to be carried out by the Chemical and Tech Center of Catalonia, funded by Repsol, (3) Pilot on the use of biofuels produced by seaweed, a research project application from Repsol laboratories, (4) Smart metering for water in neighborhoods and public swimming pools, with AGBAR, EMATSA and AQUALOGY, expecting the results of a competitive project from the European Union on telemetry, (5) New asphalt installed in zones of intensive use by heavy industrial vehicles, the properties allow capturing contaminated diesel particles, better water absorption, and fissure self-repair, and (6) Water quality control of beaches in Tarragona accessible through mobile phone and tablets apps.

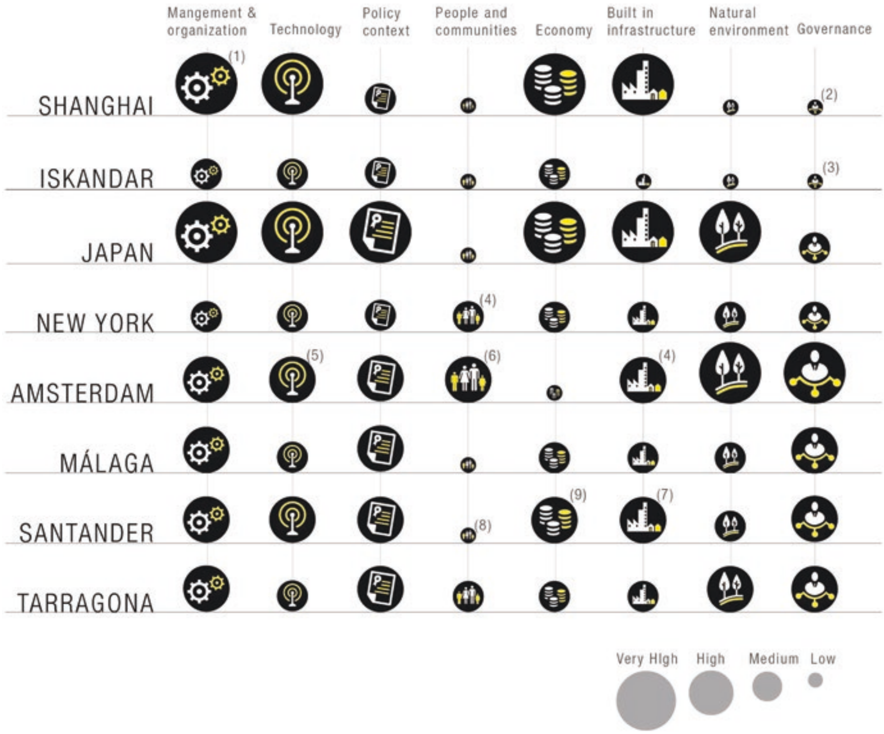
In Tarragona, we found a change that was defined by the Town Hall as going “from improvisation to programming” in environmental policies linked to the smart city project. The data collected shows that the natural environment is present in the first smart city plan. Thus, the hypothesis: that the natural environment is a key focus in the first smart city plan of Tarragona is to certain extent support by the data—and mostly focused on pilots.

Analysis and Findings from Our Cases

In our analysis of the eight smart city plans from Shanghai in China, Iskandar in Malaysia, Japan four smart city plans-Yokohama, Toyota City, Keihanna and Kitakyushu-, New York in the United States; and Amsterdam, Málaga, Santander and Tarragona in Europe, we have identified two theoretical traditions in the study of smart cities, one with a focus on sociology, and a second one, engrained on technology. In both traditions we have shown that the environment is a relevant variable. Thus, Caragliu et al. (2011) when studying the smart city introduce the need of a strategic agenda for sustainable urban development as main part of the concept. Chourabi et al. (2012), from a technological background also make the natural environment a critical factor in their model. From these two perspectives we have inferred the following hypothesis: that the natural environment will be a key focus in the smart city plans unveiled by local governments, and we have proceed to test it in our eleven city cases. From this hypothesis we formulated the following questions that we have answered in each of the case studies: Is really the case that the natural environment is a focus of the smart city plan? To what extent? And, what have been the differences, if any, in smart city plans with regard to strategy and the green dimension associated with long-term goals?

From this exploration we founded interesting differences and some similarities among the cases. We find that the multifaceted sides of the green dimension in smart city plans are being established locally, to a fundamental extent from local governments, except for the particular case of the four cities in Japan and Iskandar in Malaysia, where the national governments have had a say in the smart city level plan design. The focus on how the natural environment should be addressed in the smart city plans varies in the different cases. Only in one case society engagement has been also important in the implementation: Amsterdam is the relevant case in this particular ground.

From the cases analyzed it is interesting to see that the green dimension is not strategically ingrained in long-term plans for the smart cities in the cases analyzed, except for Amsterdam. A certain approximation to natural environment is done from the perspective of energy and smart grid modernization, for instance both in Shanghai in China and cities in Japan. However, there is a lack of attention to the "green dimension" as a fundamental part of smart city plans in terms of focus. In this regard, we should stress the fact that the environment is fundamentally a focus covering energy production and emission's concerns, and technology is paramount in implementation in first smart city plans covering over eight cases worldwide. Resilience to climate change, however, is poorly addressed. The following table from Gil, Navío, and Pérez de Heredia (2015) shows the results when we compare the eight cases of the study, and our focus on the seventh dimension in this work, the natural environment, showing the extent to which smart city plans include it.



Concerns about the natural environment are, to an extent, present in the eight cases, but they are not equally central to any of the smart cities plans. We find a there is not a consistent focus on policies tackling resilience to climate change, energy consumption and reduction of emissions. As such, there is an interesting scope for improvement in policy conceptualization and design. Shanghai faces severe environmental concerns that are not addressed in their first smart city plan. Malaysia is also aware of severe environmental concerns, but there are no incentives set in place to protect and preserve the natural environment. Japan did set up the smart city pilots in the aftermath of the nuclear accident, and in those efforts made the environment an important concern. New York suffered the impact of climate change brought by hurricane Sandy in November 2012 and plans focus on computer simulations for weather forecasts, updating government data management and efficiency. Energy consumption and reduction of emissions are less of a focus in New York though. In the European cities, Amsterdam, Málaga, Santander, and Tarragona we find some concerns about the environmental dimension translated into smart city plans, in particular on energy consumption and reduction of emissions. Smart policies here address transport issues in all cases. In Malaga, where research on electric batteries and electric cars is some of the smart pilots, we found some similarity with Japan. Amsterdam is concerned with energy and through the use of citizen engagement initiatives, citizens have been given a role in defining a possible new model of energy democratization. Málaga is developing modern metering, Santander is experimenting with sensors, and the Internet of Things and Tarragona is concerned with the chemical industry and transport efficiency. The public policies proposed with regard to the environment and the partnerships to attain them are varied in the over eight cases examined.

Our hypothesis, that the natural environment is a key focus in the smart city plans analyzed, has not been supported in the cities that were the focus our case studies, except for cities in Japan -under the Yokohama, Toyota City, Keihanna and Kitakyushu smart city plans- and the city of Amsterdam. Our analysis has shown the different ways the natural environment is addressed in these plans, and shows a consistent lack of attention to the green dimension in smart city plans. We may also point out the interest to take into account three sources of environmental ethics, covering resilience to climate change, energy consumption, and reduction of emissions in future plans for smart cities. There is much to be gained from smart city plans where technology as tactics is ingrained in long-term strategy addressing environmental ethics and sustainability, which is actually lacking to a great extent at the moment of the cases studied. There is also need for research that addresses these issues in a consistent manner.

In our cases studies, we found shortcomings in the data in each case to validate the hypothesis, namely, that the natural environment is focal in each smart city plan, because there were other variables, unrelated to the environment, key to the smart city plans. This is supported by the case analysis, except for cities in Japan and Amsterdam, where the environment was paramount. We also find a lack of further commitments, as evaluations of the smart city plans have not been published. Further, we find plans that once finished, have not been renewed. The lack of evidence in our cases on the natural environment being a focus of the smart city plans, and the lack of evaluation and further redraft of future plans make the conclusions of this work more valuable: first of all, there is a need to draw a necessary link between smartness and the environment in order to tackle challenges derived from sustainability at the local level, in line with the work of García Fernandez and Peek (2020). Efforts might also be placed to ingrain the green dimension and the environmental challenges we face in technological leaps forward. The work might also be extended in the line suggested by Jax, Calestani, Chan, et al. (2018), and embed the green dimension in smart city plans in a broader and richer set of human relations with nature, which transcends the distinction between instrumental and intrinsic values. In the view of Jax et al. (2018) this perspective considers both the question of what nature does for people and also acknowledges a diverse set of other relationships with nature and the values associated with it. It might also be extended in the sense precluded by Himes and Muraca (2018), allowing for the operationalization of relational values into frameworks for ecosystem services and nature's benefits to people in different local contexts.

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Part III
Innovations in Smart Cities

A Methodology for Participatory Planning of Smart City Interventions

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Abstract The development of smart cities is a highly difficult undertaking, which requires participation and cooperation of several stakeholders, both in its planning, due to the multiplicity of possible smart city interventions available as options, and also in its implementation, due to its high complexity. Especially for planning (selecting and prioritizing) specific smart city actions to be implemented it is necessary to combine knowledge: (1) on one hand from the university and the industry, concerning the possible smart city interventions, the capabilities they can offer in general, as well their difficulties and challenges; (2) and on the other hand from the municipalities and the citizens, concerning the 'real-life' benefits and value that these possible interventions can actually provide, and their potential for addressing specific challenges, problems and needs of modern cities. However, there is a lack of sound methodologies for this required participatory planning of smart city interventions. This chapter contributes to filling this gap, by presenting a methodology for this purpose. It is based on a detailed taxonomy of possible smart city actions, which we have developed through a review of relevant literature, representing knowledge that has been developed in this area by the university and the industry, who can be viewed as the smart city actions' supply side. This taxonomy is used for collecting assessment data from municipalities as well as citizens concerning these possible smart city actions, which incorporate relevant knowledge and preferences of municipalities and citizens, who can be viewed as the smart city actions' demand side). Our

The original version of this chapter was revised. The correction to this chapter is available at https://doi.org/10.1007/978-3-030-61033-3_17

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_8

methodology includes three layers of processing the above municipalities' and citizens' assessment data, which reveal: (a) the perceptions and priorities of these two important stakeholders concerning smart city actions (layer I–II respectively); and (b) points of convergence as well as points of divergence between them (layer III). These enable a rational participatory planning of smart city interventions. Our methodology has been applied in the context of Greece: assessment data concerning the above possible smart city actions have been collected from 144 Greek municipalities and 500 citizens, and their processing has led to interesting conclusions, which can be quite useful for planning the next steps of smart cities' development in Greece.

Keywords Smart city interventions · Participatory planning methodology · Smart city actions taxonomy · Stakeholder engagement

Introduction

There has been an increasing urbanization in the last decades, which has increased significantly the share of world population living in cities, as well as the share of world Gross Domestic Product (GDP) generated in cities (OECD, 2012, 2018). According to a study of the European Parliament (2014) more than half of the world's population live in cities, and this rises to over two thirds in EU28, while these proportions are continuously growing. This has not only positive but also negative aspects as well, giving rise to the emergence of serious social, environmental and economic challenges and problems that have to be addressed (Axelsson & Granath, 2018; Chourabi et al., 2012; Dameri, Negre, & Rosenthal-Sabroux, 2016; Nam & Pardo, 2011a, 2011b). High density city populations increase strains on energy, transportation, water, buildings and public spaces, services, etc., so solutions for these need to be found which are 'smart', i.e., highly efficient, effective and sustainable; at the same time it becomes imperative to generate economic activity, employment and social wellbeing for these increasing populations. Information and communications technologies (ICT) can be a key enabler for cities to address these challenges and problems in a 'smart' (i.e., efficient, effective, and sustainable) manner. It is quite important to exploit the extensive capabilities of the ICT in order to support novel smart approaches and practices to addressing these inherent serious challenges and problems of modern cities, and this has led to the development of the smart cities. Hall (2000) defines the Smart City as 'a city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rail/subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens. Emergency response management to both natural as well as man-made challenges to the system can be focused and rapid. With advanced monitoring systems and built-in smart sensors, data can be collected and evaluated in real time (Anthopoulos et al., 2016), enhancing city management's decision-making. The abovementioned study of the European Parliament (2014) defines smart city as 'a city seeking to address public issues via ICT-based solutions on the basis of a multi-stakeholder, municipally based partnership', and then continues by stating that in a smart city 'ICT links and strengthens networks of people, businesses, infrastructures, resources, energy and spaces, as well as providing intelligent organizational and governance tools'. The International Telecommunication Union (ITU) of the United Nations, based on an analysis of many existing definitions of smart cities, has developed the following definition (that has been officially approved by the ITU): 'A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects' (Kondepudi et al., 2014). Smart cities make increasingly use of the Internet of Things (IoT) technologies, installing various types of sensors in city's infrastructures, which generate large amounts of useful data that can be quite useful both for monitoring and services provision, and also for making longer planning (Silva, Khan, & Han, 2018).

The first attempts for the development of smart cities were mainly fragmented top-down technology–led projects, driven mainly by strong ambitions of some politicians, who were interested in improving their personal image as forward-looking technology promoters, and also by marketing and promotion efforts of ICT vendors, who were interested in promoting specific technological solutions. The experience gained from these first attempts, in combination with the limited benefits and value generated by them, lead to a better understanding of their inherent difficulty, complexity and multi-dimensionality, which necessitates the adoption of a more participatory development approach. So, it is gradually recognized that the development of smart cities is a highly difficult undertaking, which requires participation and cooperation of several stakeholders, both in its planning, due to the multiplicity of possible smart city interventions available as options, and also in its implementation, due to its high complexity (Axelsson & Granath, 2018; Dameri, 2017; Leydesdorff & Deakin, 2011; Silva et al., 2018). Furthermore, it has been suggested that the development of smart cities should be based on a 'triple helix' approach, which includes cooperation of government, industry and university actors, or even on a 'quadruple helix' approach, which involves additionally the citizens (Axelsson & Granath, 2018; Dameri, 2017; Carayannis & Campbell, 2009). Especially for planning (selecting and prioritizing) specific smart city actions to be implemented it is necessary to combine knowledge: (1) on one hand from the university and the industry, who can be viewed as the smart city actions' supply side, concerning the possible smart city interventions, the capabilities they can offer in general, as well their difficulties and challenges; (2) and on the other hand from the municipalities and the citizens, who can be viewed as the smart city actions' demand side, concerning the 'real-life' benefits and value that these possible interventions can actually provide, and their potential for addressing specific challenges, problems and needs of modern cities.

However, there is a lack of sound methodologies for this required participatory planning of smart cities interventions (Castelnovo, Misuraca, & Savoldelli, 2016; Dameri, 2017). Though some methodologies have been developed concerning citizens' participation in individual smart city actions and especially the coproduction of public value in cooperation with municipal authorities (Allen, Tamindael, Bickerton, & Cho, 2020; Castelnovo et al., 2016; Webster & Leleux, 2018), e.g., through urban labs, living labs, citizen panels, hackathons, citizen dashboards, open datasets, online voting and consultations, there is a lack of methodologies concerning citizens' participation in the higher level planning of smart city actions: in the selection and prioritization of the specific smart city actions to be implemented. This is an important research gap, given the widely recognized need for socially (and not technocracy) rooted 'human smart cities' (Oliveira & Campolargo, 2015), which are oriented toward addressing human needs and problems. This chapter contributes to filling this gap, by presenting a methodology for the participatory planning of smart city interventions, enabling the elicitation and integration of citizens' opinions and preferences in relevant. It is based on a detailed taxonomy of possible smart city actions, which we have developed through a review of relevant literature, representing knowledge that has been developed in this area by the university and the ICT industry (who can be viewed as the smart city actions' supply side). This taxonomy is used for collecting assessment data from municipalities as well as citizens concerning the usefulness and importance perceived by them for a wide range of possible smart city actions, which incorporate municipalities' and citizens' (who can be viewed as the smart city actions' demand side) relevant knowledge and preferences. Finally, our methodology includes three layers of processing of the above municipalities' and citizens' assessment data, which reveal: (a) the perceptions and priorities of these two important stakeholders concerning smart city actions (layer I–II respectively); and (b) points of convergence as well as points of divergence between them (layer III). These enable a rational participatory planning of smart city interventions, based on actions for which there is a convergence between municipalities and citizens concerning their high priority; also, they enable identification of smart city interventions for which consultation is required between municipalities and citizens as there is divergence about their priority level. Our methodology has been applied in the context of Greece: assessment data concerning possible smart city actions have been collected from 144 Greek municipalities and 500 citizens, and their processing lead to interesting conclusions, which can be quite useful for planning the next steps of smart cities' development in Greece.

Therefore, this chapter makes three important contributions:

(1) Development of a detailed taxonomy of possible smart city actions, much more detailed and comprehensive than the existing ones, which can be quite useful not only as a foundation of our methodology (see contribution (2) below), but also beyond it as well, as a foundation of future research in this area, and also for strategic planning of such actions by government agencies (such as municipalities). (2) Development of a methodology, based on the above taxonomy, for collecting assessment data from municipalities and citizens concerning the usefulness and importance perceived by them for a wide range of possible smart city actions, and then processing them in order to understand better relevant perceptions and priorities of these two important stakeholder groups, as well as points of convergence and divergence (agreement and disagreement) between them; the points of convergence (agreement) can be used as bases for participatory planning of smart city interventions, while the points of divergence (disagreement) can be used as a base of consultation between municipalities and citizens in order to promote mutual understanding

and finally consensus building on future smart city actions' priorities. (3) A first application of the above methodology, which provides a validation of its usefulness and value, and leads to interesting conclusions.

This chapter is structured in six sections. In the following Section "Background", the background of our research is presented, while the proposed taxonomy of possible smart city actions we have developed is described in Section "A Taxonomy of Smart City Actions", and then the proposed methodology in Section "A Participatory Planning Methodology". Its first application is presented in Section "Application", and finally the conclusions are summarized in Section "Conclusions".

Background

There has been considerable literature on the conceptualization of smart cities, attempting to identify the major elements of them. A study conducted by the Centre of Regional Science of the Vienna University of Technology (Giffinger, Fertner, Kramar, Meijers, & Pichler-Milanovic, 2007) identified six basic thematic areas of smart city: smart economy (aiming at improving the competitiveness of local firms), smart people (for improving social and human capital), smart governance (facilitating and promoting citizens' participation in public life), smart mobility (aiming at sustainable, innovative and safe city transport systems), smart environment (for environment protection and natural resources management) and smart living (for improving quality of life in several areas, such as housing, health, education, culture and safety). Based on the previous study, Cohen (2014) elaborated its thematic areas, and developed a second layer including more areas, such as smart buildings, resource management, online services, health, safety and open government, as well as the definition of indicators about them. The IBM Institute for Business Value in a study concerning 'A vision for smarter cities' (Dirks & Keeling, 2009) suggest that the main elements of smart cities should correspond to the six main core systems of modern cities, aiming to improve their efficiency and effectiveness: people (human and social networks, public safety (police, fire and disaster recovery), health, education and quality of life); business (improvement of competitiveness of city's business ecosystem, as well as its openness to foreign trade and investment, and balance of complex regulatory requirements with the need to minimize firms' unnecessary administrative burdens); transport (all aspects of road network, public transport network and sea/air ports, from provision to pricing); communication (telecommunications infrastructure, including telephony, broadband and wireless); water (the entire water cycle, water supply and sanitation, with emphasis on addressing problems with water efficiency, leakage, quality and the threat of flooding, which pose a significant threat to cities' sustainability); and energy (power generation and transmission infrastructure, as well as its waste disposal).

Nam and Pardo (2011a) conceptualize smart cities along three dimensions: technological (digital, wired, ubiquitous and intelligent city—integration of infrastructures and technology-mediated services), human (social learning for strengthening human infrastructure—social capital) and institutional (institutional improvement concerning governance, policy, regulations/directives, as well as citizen engagement); the development of each of them and also their linkages can define a smart city. Chourabi et al. (2012) describe an integrative framework for the characterization and development of smart cities initiatives, which includes the following eight elements as well as their interconnections: policy, organization and technology (inner-cycle elements), and also people communities, economy, governance, natural environment and infrastructure (outer-cycle elements). Hancke, de Carvalho e Silva, B., and Hancke Jr. (2013) focus on the main elements of a smart system that can be developed using sensors; they conclude that the most important of them are: smart infrastructure, smart surveillance, smart electricity and water distribution, smart buildings, smart healthcare, smart services and smart transportation.

The International Telecommunication Union (ITU) of the United Nations identifies three main parameters for the development of a sustainable city (Kondepudi et al., 2014); in particular, they argue that '…to make sure that there is an overall development of energy, health care, buildings, transport, and water management in a city: (a) environmental care, with right technologies, cities will become more environmentally friendly; (b) competitiveness, with the right technologies, cities will help their local authorities and businesses to cut costs and (c) quality of life, with the right technologies, cities will increase the quality of life for their residents'. Also, they identified the following eight elements to be of critical importance for the development of smart cities: (1) quality of life and lifestyle, (2) infrastructure and services, (3) ICT, communications, intelligence and information, (4) people, citizen and society, (5) environment and sustainability, (6) governance, management and administration, (7) economy and Finance, and (8) mobility. Recently, Silva et al. (2018), based on a review of previous literature on smart cities, propose a generic smart city architecture, which consists of four layers: sensing layer, transmission layer, data management layer, and application layer; the latter includes several smart applications, with the most important of them being smart communities development, smart buildings, smart water management, smart waste management, smart road, train, water and air transportation, and also smart healthcare.

From the above literature reviewed in this section, it is concluded that multiple conceptualizations of a smart city exist, which propose important elements of a smart city, so a synthesis of them is required, as well as further elaboration of them, in order to develop a taxonomy of possible smart city actions, to be used as a basis of a methodology for participatory planning of smart city interventions, as described in the following Section "A Taxonomy of Smart City Actions". However, given the big number of possible smart city actions that can be implemented by municipalities, and the limited financial resources available, it is important to be selective by focusing and placing priority on the most beneficial ones for the society: in order to identify them the views of all stakeholders should be taken into account, and especially the ones of citizens. It is highly important as the smart city actions' planning (i.e., the selection and prioritization of them) reflects not only ambitions of some politicians (who usually focus on impressive actions, supporting their 'political marketing', but not on substantial ones that are more beneficial for the society), or the promotion plans of ICT firms (who usually focus on promoting specific products according to their marketing priorities); it is imperative that citizens' relevant perceptions, needs and preferences, as well as knowledge and ideas, should also be taken into account. This is in line with the more general trend of citizens' participation in government planning, policy making and even budgeting, in order to make them more socially rooted and responsive to citizens' problems, needs and values, and also exploit the 'wisdom of the crowd' (citizens' knowledge and ideas), and even co-create value with citizens, advancing toward a more open, participative, collaborative and smart government (Allen et al., 2020; Brun-Martos & Lapsley, 2017; Ferro, Loukis, Charalabidis, & Osella, 2013; Loukis, Charalabidis, & Androutsopoulou, 2017; Noveck, 2015; Webster & Leleux, 2018); for this purpose government agencies use a variety of techniques, both quantitative (mainly questionnaire-based surveys) and qualitative (such as focus groups—citizen panels, urban/living labs, consultation spaces, social media). However, though some methodologies have been developed concerning citizens' participation in individual smart city actions and co-production of public value through cooperation between citizens and municipal authorities (Allen et al., 2020; Castelnovo et al., 2016; Webster & Leleux, 2018), there is a lack of methodologies for citizens' participation in the higher level planning of smart city actions: for the participatory planning of smart cities interventions (Castelnovo et al., 2016; Dameri, 2017).

A Taxonomy of Smart City Actions

A taxonomy of smart city actions has been developed based on previous research concerning the main elements of a smart city, which has been reviewed in the previous Section "Background" (Chourabi et al., 2012; Cohen, 2014; Dirks & Keeling, 2009; Giffinger et al., 2007; Hancke et al., 2013; Kondepudi et al., 2014; Nam & Pardo, 2011a; Silva et al., 2018; Gil-Garcia et al., 2015). It includes ten thematic categories of actions, which concern: ICT infrastructure, environment, transportation-mobility, health, waste management and water resources, energy—sustainable development, tourism and culture, economy—development, security and e-government; each of them includes specific actions, so the taxonomy includes 59 actions in total. They are shown in Table 1. This taxonomy constitutes a sound foundation for our methodology (presented in the following Section "A Participatory Planning Methodology"): for the collection of data about the perceptions of the municipalities and citizens concerning the usefulness and the importance of a wide range of possible smart city actions, enabling the identification of relevant convergences and divergences; the former can be used as a basis for participatory planning of smart city interventions, while the latter can be used as a basis for starting a relevant debate and consultation between municipalities and citizens aiming at increasing mutual understanding and finally consensus building on future smart city actions' priorities.

Table 1 Smart city actions' taxonomy

Category	No	Actions
(1) ICT Infrastructure	1.1	Implementation of free Wi-fi in municipal buildings and public areas
	1.2	Implementation of optical fiber network (MAN)
	1.3	Data center infrastructure for collecting and storing data from Internet of Things (IoT) sensors
	1.4	Hardware and software upgrade in the municipal offices for a highly efficient back-office
	1.5	Electronic document flow management system for municipal offices
	1.6	Info-kiosks installation for providing information to citizens and visitors
	1.7	Installation of electronic boards providing information in real time (such as weather, local news, events and duty pharmacies)
(2) Environment	2.1	Installation of electromagnetic radiation measurement sensors
	2.2	Installation of noise measurement sensors
	2.3	Installation of air pollution measurement sensors
	2.4	Installation of rain level measurement sensors
	2.5	Installation of atmospheric microparticles measurement sensors
	2.6	Installation of light level measurement sensors
(3) Transportation—Mobility	3.1	Actions for monitoring and improvement of traffic management in real time
	3.2	Use of intelligent systems at pedestrian crossings for safe movement
	3.3	Smart bus stops (e.g., with online bus arrival information) for better public transportation
	3.4	Installation of sensors on transportation vehicles or roads for traffic flow monitoring
	3.5	Smart traffic information signs for traffic management
	3.6	Car parking spaces' sensors providing information and guidance to drivers for parking availability
(4) Health	4.1	Implementation of health care tele-monitoring system to support vulnerable groups of people (such as disabled, suffering from Alzheimer's disease)
	4.2	Implementation of telemedicine system for measurements of key health indicators (such as pressure, blood sugar) of citizens, and medical records archive
	4.3	Implementation of patient progress remote monitoring systems in isolated areas

(continued)

Table 1 (continued)

Category	No	Actions
(5) Waste Management and Water Resources	5.1	Online quality measurement system of drinking water
	5.2	Online monitoring system with appropriate sensors for detecting possible water leaks in the water network
	5.3	Online monitoring system for immediate detection of possible water leaks in closed irrigation channels or irrigation tanks
	5.4	Actions encouraging and informing citizens about recycling through tele-education
	5.5	Online monitoring and management system of pumping and boring stations
	5.6	End-to-end irrigation management system with dam operation control, pumping stations control, and water flow control in piping
	5.7	Online waste containers' management system (with occupancy sensors) and waste collection fleet management (using GPS)
(6) Energy—Sustainable development	6.1	Installation of photovoltaics in municipal buildings
	6.2	Construction of wind farms
	6.3	Energy savings in municipal buildings by upgrading exterior wall with insulation claddings and integrated interventions in cooling and heating systems—energy consumption monitoring and management system
	6.4	Energy saving in the lighting of municipal streets and public spaces (e.g., by replacing existent lamps with led type ones, or by using a remote-control system)—smart lighting
	6.5	Actions for citizen information and awareness about energy saving through tele-education
	6.6	Optimal routing and fuel consumption monitoring of municipal transportation vehicles, and fleet management systems, for reducing fuel consumption
(7) Tourism—Culture	7.1	Development of a system for advertising and promoting local cultural ICT infrastructure and events through the municipal website
	7.2	Development of electronic local tourist guide
	7.3	Development of touristic content applications for mobiles
	7.4	Protection, promotion, and enhancement of museums, galleries, monuments, caves, archeological and historical sites through virtual tours
	7.5	Digitization of museum content for creating digital cultural footprint
(8) Economy—Sustainable Development	8.1	Actions for promoting entrepreneurship in municipal websites

(continued)

Table 1 (continued)

Category	No	Actions
	8.2	Actions for the promotion and sale of local products via municipal websites
	8.3	Employment actions via municipal websites
	8.4	Innovative actions for supporting high technology farming (e.g., precision farming)
	8.5	Promotion of innovative technological activities via municipal websites
	8.6	Interactive consulting services for young entrepreneurs in municipal web platforms
9. Security	9.1	Fires early warning and response system
	9.2	Systems for citizens' protection in emergencies (such as earthquakes and floods)
	9.3	Using ICT for security and surveillance of public buildings and facilities
	9.4	Weather conditions monitoring and forecast systems for agricultural production
(10) E-Government	10.1	Electronic voting application (e-voting) for municipal issues
	10.2	Electronic consultation on important municipal decisions and plans
	10.3	Collection of electronic signatures on important municipal issues (e-petitions)
	10.4	Electronic (online) provision of the municipal services through the municipal website
	10.5	Development of applications enabling citizens to submit requests-problems through electronic channels
	10.6	Online monitoring system for collective bodies (e.g., city council) meetings
	10.7	Free access to open data for use by individuals or other public agencies
	10.8	Geographic information systems (GIS) applications for urban planning purposes (such as land use information and objective property values)
	10.9	Implementation of e-government services provision framework

A Participatory Planning Methodology

The taxonomy of smart government actions described in the previous Section "A Taxonomy of Smart City Actions" has been used as a basis for the development of a methodology for participatory planning such actions. In particular, our methodology includes initially collection of assessment data on one hand from municipalities and on the other hand from citizens concerning the usefulness and importance perceived by them for the 59 smart city actions of the above taxonomy (see Section "Data Collection"). Then these data are processed in order to determine the perceptions and priorities of each of these two important stakeholders concerning the above smart city actions, as well as points of convergence as well as points of divergence between them (see Section "Data Processing").

Data Collection

For the above data collection, a quantitative approach was adopted: a survey based on two questionnaires that have been developed, one for municipalities (M_Questionnaire) and another one for citizens (C_Questionnaire). The municipalities' questionnaire initially includes some questions concerning the population of the city, the characteristics of the area (whether it is urban, rural, island, highland, lowland, touristic), and also demographics of the respondent (age, ICT familiarity, educational level, work experience); then it asks for each of the abovementioned 59 smart city actions of our taxonomy whether (Yes/No) it has been implemented in the particular municipality, and also whether (Yes/No) it will be implemented in the future. The citizens' questionnaire initially includes some demographic questions (age, gender, educational level, profession); then for each of the above 59 smart city actions the citizen is asked to fill in the degree of his/her agreement about the importance of the action for making a city smart in a 5-points Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree).

Data Processing

The data that will be collected from the municipalities and the citizens will undergo three layers of processing:

Municipalities' Data

The first layer of processing will include the following four processing steps of the data collected from the municipalities using the M_Questionnaire:

M1. For each municipality we calculate for each of the 59 smart city actions of our taxonomy the assessment of its importance M_ACT_IMPi (i = 1.0.59): it will take value 1 if the action has already been implemented, and 0.5 if the action has not been implemented but will be implemented in the future.

M2. For each of these 59 smart city actions its average importance over all the respondent municipalities is calculated: MAV_ACT_IMPi (i = 1.0.59); from them the average importance of each of the 10 action categories of our taxonomy for the municipalities is also calculated: MAV_CACT_IMPi (i = 1.0.10).

M3. These 59 smart city actions are sorted according to their average importance for the municipalities MAV_ACT_IMPi, and in this way the priority order of each action for the municipalities MPRO_ACTi is determined; the same is done for the ten action categories.

M4. The top 20 smart city actions with respect to the priority assigned to them by the municipalities are determined and discussed; this enables drawing interesting conclusions concerning the perceptions and priorities of the municipalities concerning smart city actions.

Citizens' Data

The second layer of processing will include the following three processing steps of the data collected from citizens using the C_Questionnaire:

C1. For each of these 59 smart city actions its average importance over all the respondent citizens is calculated: CAV_ACT_IMPi (i = 1.0.59); from them the average importance of each of the ten action categories for the citizens is also calculated: CAV_CACT_IMPi (i = 1.0.10).

C2. These 59 smart city actions are sorted according to their average importance for the citizens CAV_ACT_IMPi, and in this way the priority order of each action for the citizens CPRO_ACTi is determined; the same is done for the ten action categories.

C3. The top 20 smart city actions with respect to the priority assigned to them by the citizens are determined and discussed; this enables drawing interesting conclusions concerning the perceptions and priorities of the citizens concerning smart city actions.

Municipalities—Citizens Comparison

The third layer of processing performs a comparison of the priorities assigned to these 59 smart city actions by the municipalities with the ones assigned by the citizens, aiming to identify points of convergence and divergence between them. For this purpose, for each of the 59 smart city actions of our taxonomy the difference between the priority order assigned to it by the municipalities and the priority order assigned to it by the citizens MC_PRODIF_ACTi (i = 1.0.59) is calculated:

MC_PRODIF_ACTi = MPRO_ACTi − CPRO_ACTi

This enables us to identify:

(a) a group of smart city actions with low priority difference between municipalities and citizens, which represent points of convergence between these two important stakeholders;
(b) and also a group of smart city actions with high priority difference between municipalities and citizens, which represent points of divergence between these two important stakeholders (on one hand actions to which municipalities give

higher priority than the citizens, and on the other hand actions to which citizens give higher priority than the municipalities).

Therefore, we can we can include in our smart city development plans the actions for which there is a convergence between municipalities and citizens concerning their high priority (i.e., a subset of the actions of the above group a, for which the average of the priorities assigned by the municipalities and the citizens is high); at the same time consultation is required between municipalities and citizens concerning smart city actions for which we have divergence about their priority level (i.e., the above group b).

Application

Our methodology has been applied in the context of Greece. The municipalities' questionnaire was sent to the 325 Greek municipalities, and 144 of them returned to us valid questionnaires (response rate 44.3%): the main characteristics of them are shown in Table 2. The citizens' questionnaire was disseminated through social media and blogs, and finally we received 500 valid questionnaires. The demographic characteristics of the respondent citizens are shown in Table 3.

Municipalities

In Fig. 1 we can see for each of the 59 smart city actions of our taxonomy its average importance over all the respondent municipalities (MAV_ACT_IMPi, i = 1.0.59), while in Fig. 2 is shown the average importance for each of the ten action categories (MAV_CACT_IMPi, i = 1.0.59). The top 20 actions for the municipalities are shown in Table 4.

We remark that for the municipalities the highest importance smart city actions' category is the 'ICT infrastructure'. Three out of the top five actions belong to this category (1.1:Implementation of free Wi-Fi in municipal buildings and public areas; 1.4: Hardware and software upgrade in the municipal offices for a highly efficient back-office; 1.5: Electronic document flow management system for municipal offices); also, in the top 20 actions we can see three more actions from this category

Table 2 Characteristics of respondent municipalities

Less than 10.000 residents: 9.72%	Urban: 51.39%
Between 10.000 and 20.000 residents: 22.92%	Rural: 48.61%
Between 20.000 and 50.000 residents: 35.42%	Highland: 48.15%
Between 50.000 and 100.000 residents: 24.31%	Lowland: 51.85%
More than 100.000 residents: 7.63%	Island: 18.75%
	Mainland: 81.25%

Table 3 Characteristics of respondent citizens

Men: 53% Women: 47%	18–25 years: 32% 26–35 years: 22% 36–45 years: 22% 46–55 years: 19% 56–65 years: 4% Above 65 years: 1%	Students: 32% Public servants: 29% Free lancers: 18% Private sector employees:12% Unemployed: 6% Retired: 3%	Tertiary educ.:48% MSc: 31% PhD: 12% Elem./Second. educ.:9%

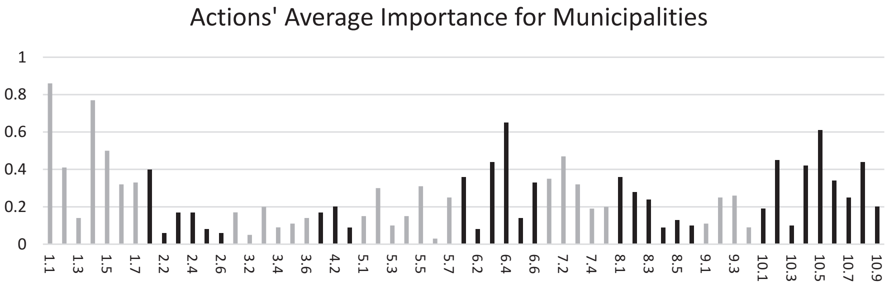

Fig. 1 Average importance for municipalities of smart city actions

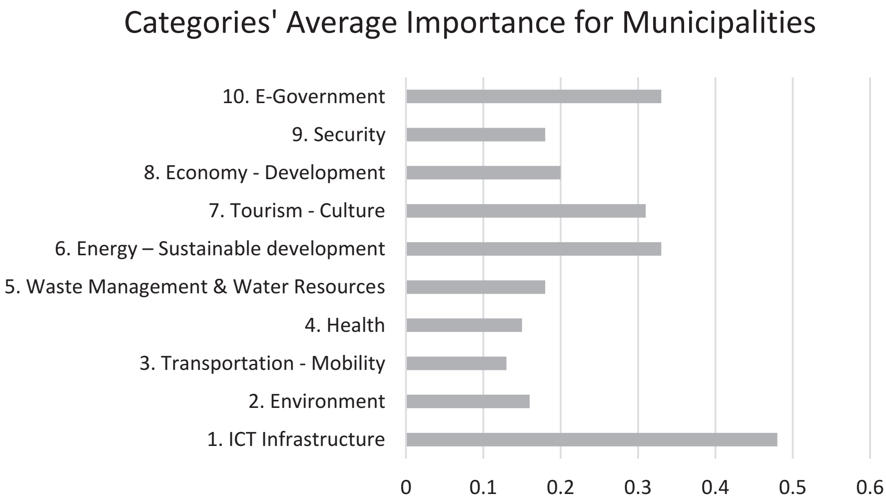

Fig. 2 Average importance for municipalities of main categories of smart city actions

(1.2; Implementation of optical fiber network (MAN); 1.7: Installation of electronic boards providing information in real time (such as weather, local news, events and on duty pharmacies); 1.6: Info-kiosks installation for providing information to citizens and visitors).

The second most important smart city actions' category for the municipalities is the 'government'. In the top five actions we can see one action from this category

Table 4 Top 20 smart cities actions for municipalities

No.	Action	MAV_ ACT_ IMP
1.1	Implementation of free Wi-fi in municipal buildings and public areas	0.86
1.4	Hardware and software upgrade in the municipal offices for a highly efficient back-office	0.77
6.4	Energy saving in the lighting of municipal streets and public spaces (by replacing existent lamps with led type ones, or by using a remote-control system)—smart lighting	0.65
10.5	Development of applications enabling citizens to submit requests-problems through electronic channels	0.61
1.5	Electronic document flow management system for municipal offices	0.50
7.2	Development of electronic local tourist guide	0.47
10.2	Electronic consultation on important municipal decisions and plans	0.45
6.3	Energy savings in municipal buildings by upgrading exterior wall with insulation claddings and integrated interventions in cooling and heating systems—energy consumption monitoring and management system	0.44
10.8	Geographic information systems (GIS) applications for urban planning purposes (such as land use information, objective property values)	0.44
10.4	Electronic (online) provision of the municipal services through the municipal website	0.42
1.2	Implementation of optical fiber network (MAN)	0.41
2.1	Installation of electromagnetic radiation measurement sensors	0.40
6.1	Installation of photovoltaics in municipal buildings	0.36
8.1	Actions for promoting entrepreneurship in municipal websites	0.36
7.1	Development of a system for advertising and promoting local cultural ICT infrastructure and events through the municipal website	0.35
10.6	Online monitoring system for collective bodies (e.g., city council) meetings	0.34
1.7	Installation of electronic boards providing information in real time (such as weather, local news, events, on duty pharmacies)	0.33
6.6	Optimal routing and fuel consumption monitoring of municipal transportation vehicles, and fleet management systems, for reducing fuel consumption	0.33
1.6	Info-kiosks installation for providing information to citizens and visitors	0.32
7.3	Development of touristic content applications for mobiles	0.32

(10.5: Development of applications enabling citizens to submit requests-problems through electronic channels), and another one in the seventh position (10.2: Electronic consultation on important municipal decisions and plans); in the top 20 actions there are three more actions from this category (10.8: Geographic Information Systems (GIS) applications for urban planning purposes (such as land use information, objective property values); 10.4: Electronic (online) provision of the municipal services through the municipal website; 10.6: Online monitoring system for collective bodies (e.g., city council) meetings). Similar importance is assigned by the municipalities to the 'Energy—Sustainable Development' smart city actions' category, with one action from this category appearing in the top five actions (6.4:

Energy saving in the lighting of municipal streets and public spaces (by replacing existent lamps with led type ones, or by using a remote-control system)—smart lighting), and also another three actions in the top 20 actions (6.3: Energy savings in municipal buildings by upgrading exterior wall with insulation claddings and integrated interventions in cooling and heating systems—energy consumption monitoring and management system; 6.1: Installation of photovoltaics in municipal buildings; 6.6: Optimal routing and fuel consumption monitoring of municipal transportation vehicles, and fleet management systems, for reducing fuel consumption). Slightly lower is the importance assigned to the 'Tourism—Culture' smart city actions' category, with three actions from this category appearing in the top 20 actions (7.2: Development of electronic local tourist guide; 7.1: Development of a system for advertising and promoting local cultural ICT infrastructure and events through the municipal website; 7.3: Development of touristic content applications for mobiles). However, we remark that much lower is the interest in the 'Economy—Development' and 'Waste Management & Water Resources' action categories, and even lower in the 'Security', 'Environment', 'Health' and 'Transportation-Mobility' ones.

Therefore, it can be concluded that the priorities of the municipalities concerning the development of smart city are ICT infrastructure actions, mainly for providing electronic support of their own internal functions, and also electronic information and Internet access to citizens, as well as e-government actions, enabling mainly electronic provision of municipal services, electronic consultation between municipality and citizens, and electronic submission of citizens' requests. On the contrary, much less importance and priority is assigned to more ambitious and complex smart city actions that extend beyond the municipality, aiming to support and improve important functions of the city, such as the transportation, the waste management and the water resources, the monitoring and protection of the environment, the health and security services.

A possible explanation for this might be that the latter actions are more complex, difficult and costly, as they necessitate the installation of various types of sensors in various infrastructures and points of the city, and also their interconnection through appropriate networks with central systems for collecting data from them, and then performing advanced processing of these data. These probably require the use of novel and therefore higher risk technologies of lower maturity, and also relevant knowledge, skills and experience that municipalities currently do not possess. On the contrary, the municipalities possess sufficient knowledge, skills and experience for the more traditional and mature technologies required for the above ICT infrastructure and e-government actions, as they are to some extent similar to relevant actions they have successfully implemented in the past; these more traditional technologies are regarded by them as more familiar and less risky.

Summarizing, the municipalities seem to have a rather narrow vision of smart city development, driven mainly by their existing knowledge, skills and experience base, and much less by the needs of their cities, oriented toward less ambitious and risky actions, which concern mainly activities of the municipality itself, and much less the important functions of the city.

Citizens

In Fig. 3 we can see the average importance for each of the 59 smart city actions of our taxonomy over all the respondent citizens (CAV_ACT_IMPi, i = 1.0.59), while in Fig. 4 is shown the average importance for each of the ten action categories (CAV_CACT_IMPi, i = 1.0.59). The top 20 actions with respect to the priority assigned to them by the citizens are shown in Table 5.

We remark that for the citizens the highest importance smart city actions' category is the 'Health'. One out of the top five actions belong to this category (4.3: Implementation of patient progress remote monitoring systems in isolated areas), while the remaining two actions of this category are among the top 20 actions (4.1:

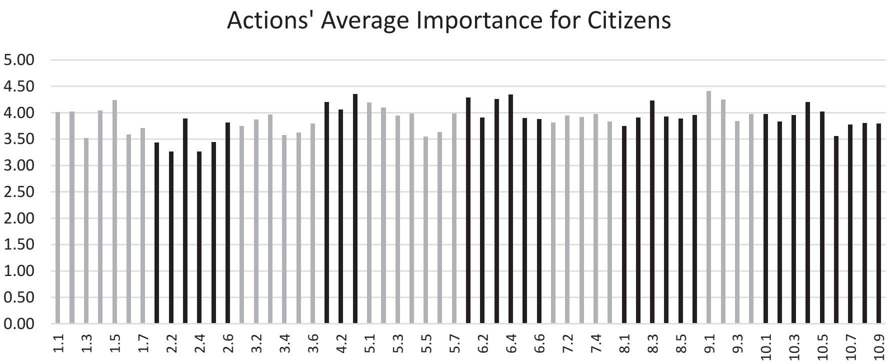

Fig. 3 Average importance for citizens of smart city actions

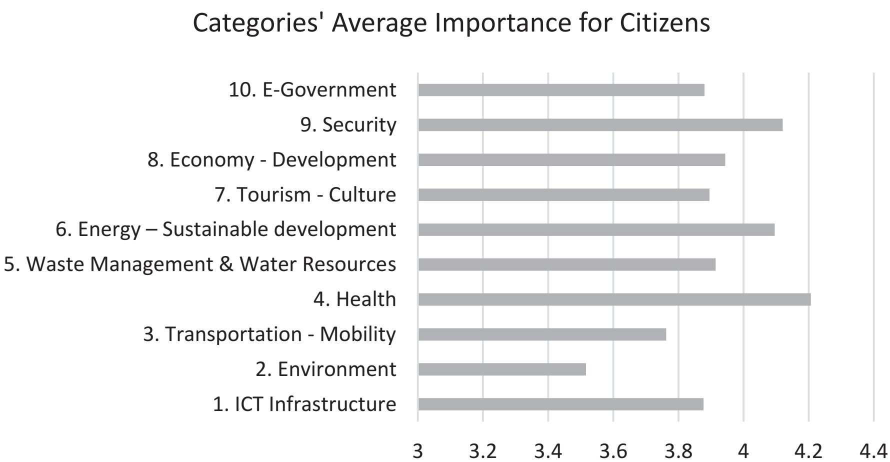

Fig. 4 Average importance for citizens of main categories of smart city actions

Table 5 Top 20 smart cities actions for citizens

No.	Action	CAV_ ACT_ IMP
9.1	Fires early warning and response system	4.41
4.3	Implementation of patient progress remote monitoring systems in isolated areas	4.36
6.4	Energy saving in the lighting of municipal streets and public spaces (by replacing existent lamps with led type ones, or by using a remote-control system)—smart lighting	4.34
6.1	Installation of photovoltaics in municipal buildings	4.28
6.3	Energy savings in municipal buildings by upgrading exterior wall with insulation claddings and integrated interventions in cooling and heating systems—energy consumption monitoring and management system	4.26
9.2	Systems for citizens' protection in emergencies (such as earthquakes, floods)	4.25
1.5	Electronic document flow management system for municipal offices	4.24
8.3	Employment actions via municipal websites	4.23
4.1	Implementation of health care tele-monitoring system to support vulnerable groups of people (such as disabled, suffering from Alzheimer's disease)	4.20
10.4	Electronic (online) provision of the municipal services through the municipal website	4.20
5.1	Online quality measurement system of drinking water	4.20
5.2	Online monitoring system with appropriate sensors for detecting possible water leaks in the water network	4.10
4.2	Implementation of telemedicine system for measurements of some key indicators (such as pressure, blood sugar) of citizens, and medical records archive	4.06
1.4	Hardware and software upgrade in the municipal offices for a highly efficient back-office	4.04
1.2	Implementation of optical fiber network (MAN)	4.02
10.5	Development of applications enabling citizens to submit requests-problems through electronic channels	4.02
1.1	Implementation of free Wi-fi in municipal buildings and public areas	4.01
5.4	Actions encouraging—informing—citizens about recycling through tele-education	3.99
5.7	Online waste containers' management system (with occupancy sensors) and waste collection fleet management (using GPS)	3.98
10.1	Electronic voting application (e-voting) for municipal issues	3.98

Implementation of health care tele-monitoring system to support vulnerable groups of people (such as disabled, suffering from Alzheimer's disease); 4.2: Implementation of telemedicine system for measurements of some key health indicators (such as pressure, blood sugar) of citizens, and medical records archive). The second most important smart city actions' category for the municipalities is the 'Security', with the highest importance action belonging to this category (9.1: Fires early warning and response system), and also another action of this category appearing in the top 20 actions (9.2: Systems for citizens' protection in emergencies (such as earthquakes, floods)). Similar importance has been assigned by the citizens to the 'Energy—Sustainable Development' smart city actions' category; three actions of this category are among the top five actions (6.4: Energy saving in the lighting of municipal streets and public spaces (by replacing existent lamps with led type ones, or by using a remote-control system)—smart lighting; 6.1: Installation of photovoltaics in municipal buildings; 6.3: Energy savings in municipal buildings by upgrading exterior wall with insulation claddings and integrated interventions in cooling and heating systems—energy consumption monitoring and management system).

Lower, however considerable, is the importance assigned by the citizens to the 'Economy—Development' and 'Waste Management & Water Resources' as well, followed closely by three smart city actions' categories that are among the top ones for the municipalities (as mentioned in the previous section "Municipalities"): 'Tourism-Culture', 'e-government' and 'ICT infrastructure'. Therefore, it can be concluded that the priorities of the citizens with respect to smart cities development cover a wider range of city functions and services, such as health services provision, protection from fires, bad weather conditions and other emergencies, development of economic activity and employment, water provision (both for drinking and for irrigation) and waste management. These priorities correspond to big 'real-life' problems and challenges that Greek citizens face (especially recently), such as poor health services, big disasters from fires, increasing consumption and cost of energy, economic crisis and recession leading to increased unemployment and poor government services (both at the levels of central government and municipalities). Summarizing, the citizens seem to have a broader vision of smart city development than the municipalities, which concerns a wider range of city functions, and is driven by important problems and needs that citizens face. The importance and priority that citizens assign to possible smart city actions is shaped by the perceived benefits and value they can provide to important city functions for addressing significant citizens' problems and needs.

Municipalities—Citizens Comparison

A comparison of the findings presented in the previous Sections "Municipalities" concerning municipalities and "Citizens" concerning citizens reveals on one hand some convergences between them, but on the other hand more divergences. A first-level basic comparison can be made by comparing the top three smart city action categories and the top 20 actions of the municipalities with the corresponding ones of the citizens. From the comparison of the top three smart city action categories for the municipalities (see Fig. 2) with the top three ones for the citizens (see Fig. 4) we can identify only one common category, for which there is convergence between municipalities and citizens: the 'Energy—Sustainable Development' smart city actions; the other two top categories differ (ICT infrastructure and e-government for the municipalities—health and security for the citizens). Also, from the comparison of the top 20 smart city actions for the municipalities (see Table 4) with the top 20 ones for the citizens (see Table 5) we can identify nine common ones, while the remaining 11 ones differ. The nine common smart city actions, for which there is convergence between municipalities and citizens about their importance (through they might have different positions in the two top 20 actions lists), are:

- 1.1: Implementation of free Wi-Fi in municipal buildings and public areas
- 1.2: Implementation of optical fiber network (MAN)
- 1.4: Hardware and software upgrade in the municipal offices for a highly efficient back-office
- 1.5: Electronic document flow management system for municipal offices
- 6.1: Installation of photovoltaics in municipal buildings
- 6.3: Energy savings in municipal buildings by upgrading exterior wall with insulation claddings and integrated interventions in cooling and heating systems—energy consumption monitoring and management system
- 6.4: Energy saving in the lighting of municipal streets and public spaces (by replacing existent lamps with led type ones, or by using a remote-control system)—smart lighting
- 10.4: Electronic (online) provision of the municipal services through the municipal website
- 10.5: Development of applications enabling citizens to submit requests-problems through electronic channels.

So, a first smart city participatory planning approach might be based on these nine actions.

A second-level more sophisticated comparison between municipalities' and citizens' priorities concerning smart city actions can be made, as mentioned in section "Municipalities—Citizens Comparison", by calculating for each of the 59 smart city actions of our taxonomy the difference between the priority order assigned to it by the municipalities and the priority order assigned to it by the citizens (MC_PRODIF_ACTi, i = 1.0.59); the results are shown in Fig. 5. The average value of the absolute value of this priority order difference over all 59 actions is 17.28: this means that the priority orders assigned to these actions by the municipalities and the citizens differ on average by 17.28 positions, which indicates in general some divergence between these two important stakeholders.

From Fig. 5 we can identify 11 actions for which there is very high divergence, with this difference exceeding 30 positions. For three of them the difference is positive (i.e., the priority assigned by the citizens is higher than the priority assigned by the municipalities):

- 4.3: Implementation of applications for remote monitoring of patient progress in remote—isolated—areas
- 9.1: Fires early warning and response system
- 9.4: Weather conditions monitoring and forecast systems for agricultural production.

For the remaining 8 the difference is negative (i.e., the priority assigned by the municipalities is higher than the priority assigned by the citizens)

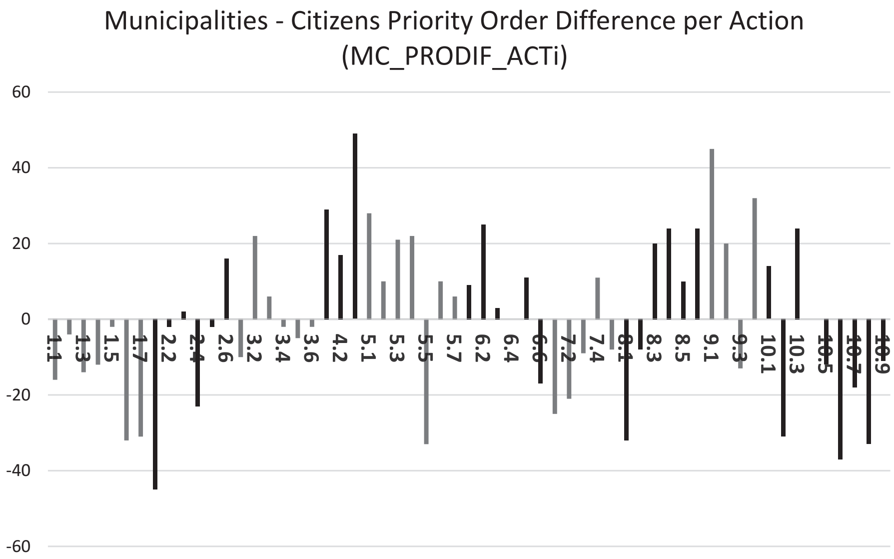

Fig. 5 Difference of priority order assigned by municipalities and citizens to smart city actions

- 1.6: Info-kiosks installation for providing information to citizens and visitors
- 1.7: Installation of electronic boards providing information in real time (such as weather, local news, events, on duty pharmacies)
- 2.1: Installation of electromagnetic radiation measurement sensors
- 5.5: Online monitoring and management system of pumping and boring stations
- 8.1: Actions for promoting entrepreneurship in municipal websites
- 10.2: Electronic consultation on important municipal decisions and plans
- 10.6: Online monitoring system for collective bodies (e.g., city council) meetings
- 10.8: Geographic Information Systems (GIS) applications for urban planning purposes (such as land use information, objective property values).

For these 11 smart city actions, for which there is high divergence concerning their priority level, consultation is required between municipalities and citizens, in order to exchange relevant information, knowledge, perceptions, and opinions, so that a better mutual understanding between the two sides can be achieved (for this purpose citizens' panels can be organized by municipalities, in which these high divergence smart city actions can be discussed in-depth).

Also, from Fig. 5 we can identify 17 actions for which there is a good level of convergence, with this difference being lower than 10 positions; for some of them there is convergence about their high priority, while for some others there is convergence about their low priority. So, a rational smart city participatory planning approach might be based on the former actions. In, particular, among the above 17 high convergence smart city actions there are 6 high priority ones, with the average of the priority orders assigned by the municipalities and the citizens being lower than 15:

- 1.2: Implementation of optical fiber network (MAN)
- 1.5: Electronic document flow management system for municipal offices
- 6.1: Installation of photovoltaics in municipal buildings
- 6.3: Energy savings in municipal buildings by upgrading exterior wall with insulation claddings and integrated interventions in cooling and heating systems—energy consumption monitoring and management system
- 6.4: Energy saving in the lighting of municipal streets and public spaces (by replacing existent lamps with led type ones, or by using a remote-control system)—smart lighting
- 10.4: Electronic (online) provision of the municipal services through the municipal website

Also, there are four more medium-to-high priority actions, having average priority order between 15 and 30:

- 3.3: Smart bus stops (with online bus arrival information) for better public transportation
- 5.7: Online waste containers' management system (with occupancy sensors) and waste collection fleet management (using GPS)
- 7.3: Development of touristic content applications for mobiles
- 8.2: Actions for the promotion and sale of local products via municipal websites.

Summarizing, the development of smart cities can start from the first six actions, and then the next four ones, in combination with consultation in order to reach consensus for more smart city actions.

The above are visualized in Fig. 6, which shows these 59 smart city actions as points in a graph having in the horizontal axis the priority order difference (absolute value) between municipalities and citizens, and in the vertical axis the average of the priority orders assigned by the municipalities and the citizens. We can see that most of these smart city action points are between priority order difference levels 10 and 40, which indicates the high level of divergence that in general exists between municipalities and citizens with respect to the importance and priority of these smart city actions; we expect that through consultation between them this divergence can decrease, and then the whole graph will move to the left. For the collaborative planning of smart city actions we have to focus on the ones located in the lower left part of this graph, which are characterized by low levels of priority order difference between municipalities and citizens, and also low average priority order (= high average priority).

Conclusions

The development of smart cities is a highly complex undertaking, and necessitates a shift from top-down planning, driven by image enhancement ambitions of some politicians, or technology promotion efforts of some ICT vendors, to participatory

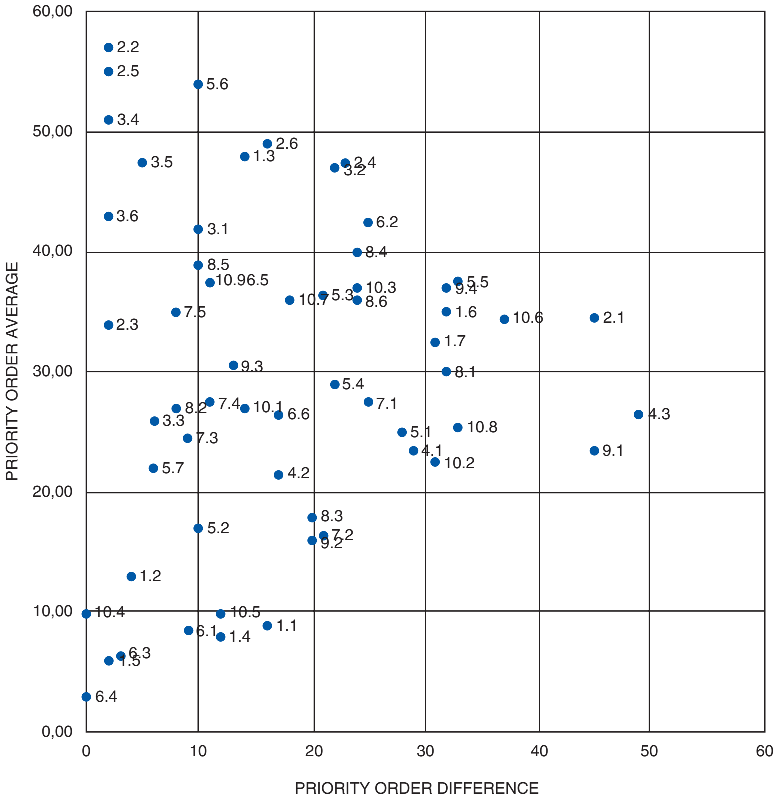

Fig. 6 Priority order average versus priority order difference for the 59 smart city actions

planning, which enables a wide range of stakeholders to contribute their relevant knowledge, perceptions and opinions. These stakeholders should represent on one hand the ‘supply side’ of smart city possible actions (such as universities and ICT industry) and on the other hand the ‘demand-side’ (possible users, such as municipalities and citizens). However, there is a lack of sound methodologies for this required participatory planning of smart city interventions. This chapter contributes to filling this gap. It presents a methodology for participatory planning of specific smart city interventions. For this purpose, we initially constructed a detailed taxonomy of possible smart city actions that have been developed by universities as well ICT industry (= supply side), based on a review of relevant literature; it consists of 10 thematic categories, which include 59 smart city actions in total. This taxonomy is used for collecting assessment data from municipalities and citizens (= demand side) concerning these possible smart city actions. These data undergo three layers of processing, which reveal: (a) the perceptions, priorities and general orientations of these two important stakeholders concerning smart city actions (layer I–II respectively); and (b) points of convergence as well as points of divergence between them (layer III). These enable combination of relevant knowledge, perceptions and opinions of the above important smart city supply side and demand-side stakeholders, as well as rational participatory planning of smart city interventions.

This methodology has been applied in the context of Greece, where assessment data concerning the above 59 possible smart city actions of our taxonomy have been collected from 144 Greek municipalities and 500 citizens. Their processing has provided interesting and practically useful insights concerning the perceptions, priorities and general orientations of these two important stakeholders concerning smart city actions. On one hand, the municipalities regard as their priorities actions concerning mainly the development of ICT infrastructures and e-government, assigning much less importance and priority to more ambitious and complex smart city actions that extend beyond the municipality, aiming to support and improve important functions of the city, such as transportation, waste management and water resources, monitoring and protection of the environment, health and security services. A possible explanation for this might be that the importance and priority they assign to possible smart city actions is shaped mainly by the degree of their familiarity with them, and much less by the benefits and value they can offer to the city. On the other hand, the citizens seem to have a broader vision of smart city development. Their priorities cover a wider range of city functions and services, such as health services provision, protection from fires, bad weather conditions and other emergencies, development of economic activity and employment, water provision (both for drinking and for irrigation) and waste management. The importance and priority that citizens assign to possible smart city actions seems to be shaped by the perceived benefits and value they can provide to important city functions for addressing significant citizens' problems and needs.

A comparison between municipalities' and citizens' priorities, perceptions and orientations reveals on one hand some convergences between them, but on the other hand more divergences. The identified convergences can be used for the rational participative planning of specific smart city interventions, while for the divergences is required consultation between municipalities and citizens, so that better mutual understanding and convergence can be achieved. In particular, for the smart city actions for which the priority assigned by the municipalities is higher than the priority assigned by the citizens it is necessary to conduct consultations with representative citizens (e.g., though urban/living labs, or focus groups—citizen panels) that aim to provide an understanding of the reasons for this divergence: it exists because citizens do not know or cannot understand all the capabilities and the value these smart city actions provide, or because they have some weaknesses that reduce their usefulness and value for the citizens? Furthermore, for the smart city actions for which the priority assigned by the citizens is higher than the priority assigned by the municipalities it is necessary to conduct similar consultations aiming to understand better the high value and usefulness of these actions that citizens perceive: do the citizens overestimate the value and usefulness of them (possible due to extensive marketing, or the 'value for money' they provide (possibly because they cannot understand the extent of financial resources and in general the effort required), or the municipality cannot understand some aspects of the value and usefulness perceived by the citizens?

Further research is required for the application of our methodology in other national contexts, and the comparison of findings with the ones of the present study; also for the extension of our taxonomy with additional smart city actions; and finally for the extension of the methodology in order to include not only quantitative data collection techniques, but also qualitative ones (such as focus groups–citizen panels, urban/living labs, consultation spaces and social media, leveraging the relevant knowledge that has been developed in the e-participation research domain—see final paragraph of section "Background"); special emphasis should be placed on the exploitation of relevant textual data (e.g., postings concerning existing or planned smart city interventions in various social media, such as Facebook, Twitter, blogs, Fora, etc.).

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An Urban Data Business Model Framework for Identifying Value Capture in the Smart City: The Case of OrganiCity

Shane McLoughlin, Giovanni Maccani, Abhinay Puvvala, and Brian Donnellan

Abstract Governments' objective to transition to "smart cities" heralds new possibilities for urban data business models to sustain and scale urban data-driven solutions that address pressing city challenges and digital transformation imperatives. Urban data business models are not well understood due to such factors as the maturity of the market and limited existing research within this domain. Understanding the barriers and challenges in urban data business model development as well as the types of opportunities in the ecosystem is essential for researchers as well as practitioners from incumbents to new entrants. Therefore, this chapter introduces a framework for understanding and classifying urban data business models (UDBM). We furthermore illustrate the application of this framework to a heterogeneous sample of emerging smart city solutions. An embedded case study method was used to derive the framework by analyzing 40 publicly funded and supported urban data focused experiments that address pressing city challenges under the H2020 OrganiCity initiative. This research contributes to the scholarly discourse on business model innovation within the context of smart cities.

Keywords Organicity · Smart city case study · Urban data business model · City values · Value creation

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_9

Introduction

The paradigm of "smart cities" as a response to increasing urban population, environmental pressures, budgetary restraints, legacy IT systems, ongoing city developments, and renewal, as well as policy and rationales for citizen participation and engagement, has opened up new possibilities for urban data focused solutions (supported by viable business models) as responses to pressing city challenges and digital transformation imperatives (Loebbecke & Picot, 2015). Here, we refer to "urban" as "relating to a town or city" (Oxford English Dictionary, 2017) and business model as the value creation logic of an organization (Osterwalder & Pigneur, 2010). Reviewing existing definitions of "urban data" (Wolff, Kortuem, & Cavero, 2015) and "urban big data" (Pan, Tian, Liu, Gu, & Hua, 2016), we define urban data as, *data concerning one or more town or city spatial region(s) physical, social, cultural, political, or economic environment*. Thus, urban data is about a town or city region(s) citizens, its infrastructure, its businesses, government, and natural environment, etc. For example, "Citymapper" acquires and exploits urban data to offer citizens the value of improved wayfinding across several European cities (Citymapper, 2019). Citymapper leverages such sources of data as citizens' geolocation, their intended destination and open urban transport data to offer its mobile app-based solution for delivering improved wayfinding. Whilst open data, citizens' smartphones and the technology behind Citymapper's app serve to enable such wayfinding, it is the business model encompassing the necessary resources, competencies, activities, and partners, etc. that sustainably delivers the solution to citizens, i.e., making Citymapper economically viable to sustain and scale.

In recent years, business activity has focused on developing pilots, demonstrating prototypes with some offering commercial solutions to cities. However, the sustaining and scaling of an ecosystem of urban data business models (UDBM) has proved slow and in some cases fraught with difficultly. Compared to previous data-driven business models (e.g., through open data from the public (Zuiderwijk & Janssen, 2015) or private (Lakomaa & Kallberg, 2013) sector or other data marketplaces), the context of urban data heralds specific technical, sociopolitical, ethical, and economic challenges, etc. Urban data may be existing data that can be purchased, reused for free or even generated through development of sensing technology or crowdsourcing initiatives. These processes create value networks comprising of different actors (Tammisto & Lindman, 2012) which significantly add complexity to business model creation (Janssen, Charalabidis, & Zuiderwijk, 2012) (Hofman, 2015). Data-Driven Urbanism (Kitchin, 2016) or "Datafication" (Maull, Godsiff, & Mulligan, 2014) of urban life therefore needs to overcome additional challenges.

Overall, digital transformation oriented around data and digital technologies (such as IoT, (web) software, cloud, AI-based analytics) is enabling service/process/product innovation, including the very processes and outcomes for achieving those innovations (OECD, 2019). As "data" becomes seen as the "new oil" and a critical source of new insight for cities, policy translating to research efforts in the EU has focused on developing a marketplace and supporting social innovation through various capacity building exercises such as policy and funding for incubators, R&D, and experimentation. Thus, the EU is playing a central role in promoting, fostering, and facilitating economic development and new business creation, centered around creating value from urban (big) data supported by digital technology innovation. Some of the most popular examples include federated Living Lab flavored initiatives like OrganiCity (Organicity, 2018) and SBIR (Small Business Innovation research) pre-commercial procurement mechanisms to support and promote (collaborative) innovation, such as among entities, sectors, businesses, and across cities themselves (Gutiérrez et al., 2016). In this regard, Governmental funding and support to "market make" new urban data ecosystems by funding research to address standards, interoperability, and encourage experimentation for innovation may lead to exponential growth of an ecosystem of innovative value propositions. In this regard, commercial vendors and social enterprises have struggled in developing sustainable business models due to continuing lags in standards, interoperability, data models, IoT (Internet of Things) and telecommunication network cost, capability, and maturity, as well as ethical concerns and budgetary constraints by cities, etc. By ameliorating roadblocks of technological standards and data models (e.g., Fireware) as well as barriers to experimentation, etc. it is hoped that a critical mass of differing urban data types and sources will unlock new opportunities for UDBM by establishing network synergy in an urban data ecosystem. "Scaling" is a crucial factor in realizing these opportunities as a minimum viable business case for a vendor could depend on multi-city/country take-up of an offering. In this regard, multi-city and multi-country experimentation by vendors is needed to develop solutions compatible across differing political–cultural–environmental–social contexts.

Finally, despite academic debate on how to conceptualize business models, there is agreement that business models articulate value creation (Hossain, 2017) communicated and delivered to customers as the "value proposition," i.e., the product or service experienced by customers. Within the recent academic literature, there have been some efforts at formulating data business model dimensions, classifications or taxonomies of: data-driven digital services (Rizk, Bergvall-Kåreborn, & Elragal, 2018), concept definitions across the data value chain (Curry, 2016), business models for open data (Ahmadi Zeleti, Ojo, & Curry, 2014), and data-driven business models (Engelbrecht, Gerlach, & Widjaja, 2016; Hartmann, Zaki, Feldmann, & Neely, 2016). However, no study has developed a framework that can apply a consistent language and lens to organizations focusing on urban data solutions. Such a framework can be fruitful for researchers as an analytical lens in (1) identifying and understanding challenges across the value network in developing UDBM, (2) identifying opportunities for new value propositions and related UDBM combinations, and (3) substantiating commercially successful types of UDBM out there. Thus, we pose the following research question:

RQ: What are the related value generating elements that inform differentiated value propositions and related urban data business models?

To address the research question, we carried out a case study the EU H2020 project OrganiCity (EU, 2017) and 40 of the experimental solutions it has funded and supported, in order to derive an urban data business model (UDBM) framework. These experiments are addressing city prescribed urban challenges, in developing innovative solutions and related UDBM, with an approach that emphasizes open innovation, co-creation, and real-world (and in some cases multi-city) experimentation methods.

The remainder of this chapter is organized as follows: Section “Related Work” overviews the related literature on business models, business model experimentation and existing frameworks, and taxonomies of data-driven business models. Section “Methodology” describes the method including the case and sample. Section “Validated Framework” describes the validated framework derived from the case study. Section “Application of the Framework” illustrates the application of the framework in characterising heterogeneous clusters of cases from OrganiCity. Finally, Section “Conclusion and Future Work” concludes by comparing the framework to existing work and identifying future research work.

Related Work

Despite the clamor for technological innovation in most advanced societies, it is often the particular business model innovation tied with the technological artifact that yields value to the innovator and the society at large. For example, Dell’s business model revolutionized computer sales in the 1990s with its direct to consumer approach. Dell’s business model innovation centered on “made to order” and “direct to consumer” computer sales, supported by an e-commerce strategy. The approach helped to ensure Dell-brought technological advancements in computer parts quickest to market, whilst eliminating the cost burden of storage and unsold inventory. Thus, consumers could access the latest technological innovations at a competitive price. A business model is an expression of the particular value creation logic of an organization (Osterwalder & Pigneur, 2010) in delivering value, both to the customer and the organization. In the case of Dell, their value creation logic centered on the resources and capabilities needed to implement a robust e-commerce strategy and business process reengineering of the assembly and logistics process in order to: eliminate inventory, reduce third-party retail venders, and bring technological advancements quick to market. Thus, a good business model is essential to ensure value for the company and the customer, differentiate the organisations approach from it’s competitors, and give a company competitive advantage.

To identify and understand business models, Osterwalder and Pigneur (2005) defined a business model as a “conceptual tool that contains a set of elements and their relationships.” These elements or key dimensions of business commonly include: the resources, capabilities and activities needed to capture value and deliver the product or service (the value proposition); the cost structure and revenue stream and the needed partners beyond its organizational boundary, as well as the customer relationship and channels of interaction. The characteristics of these key elements and their relationship for a particular organization are strongly influenced by the values and mission of the organization and its external environment including: the customer, the competitive environment, government policies and regulations, economic conditions, and available resources, etc. However, business model elements are static and often fail to give a sense of firms in action.

The dynamic perspective is key to identify an organizations journey towards establishing a sustainable competitive advantage. However, the two widely accepted views—industry positioning view and dynamic capability view discuss the conditions for competitive advantage but do not elaborate on the journey towards it (McGrath, 2010). The industry positioning view proposes a truly differentiated position within an economic environment that can be defended to achieve competitive advantage (Porter, 1991). The dynamic capability view argues that such an advantage can only be attained by developing competencies or capabilities that are hard to replicate by others (Teece, 2007). Moreover, McGrath (McGrath, 2010) argues that business model innovation for attaining competitive advantage can be strictly categorized neither as a positional approach nor as a capabilities approach. In a fast dynamic setting of technology-based businesses, it is often impossible to visualize factors and constraints that eventually prove to be competitively important at the time that decisions pertaining to business model innovation need to be made. In such cases, experimentation is the preferred strategists' tool of choice over analysis. In addition, business models' evolution is path dependent—early experiments and/or decisions often shape the future business model (McGrath, 2010).

We also draw from the business ecosystems' literature for this study. The ever-growing interconnectedness associated with the networked economy prompted the research community to refocus on business ecosystems (Moore, 1993). Moore (1993) explains business ecosystems as an allegory of natural ecosystems in order to present the way companies should do business together. Ecosystems comprise of multiple actors working together that contribute to the ecosystem's core purpose despite having seemingly unrelated value propositions. Hence, the business ecosystem view includes a network of actors unlike that of a conventional value chain view which focuses on delivering a single value proposition to the end customer (Baghbadorani & Harandi, 2012). From an ecosystem point of view, we next review frameworks that map actors of business ecosystems that are closely connected to the urban data ecosystem. Table 1 has a snapshot of related studies in domains where data plays a vital role.

Hartmann et al. (2016) framework deals with data-driven business models. Their study defines data-driven business models as the businesses with data as a key resource. Though, Hartmann et al. (2016) acknowledge that this criterion used for determining whether a business model is data-driven or not is ambiguous, given the ubiquitous importance of data to all the business models. Moreover, despite the use of multiple case studies to cluster business models, the framework development lacks inductive case study-based reasoning to develop the framework insofar as the design was based on a review of existing literature. Moreover, the framework's characterization of various second order elements leave scope for redundancies which in turn translate in to multicollinearities between explanatory variables during cluster analysis. Hartmann et al. (2016) have developed a similar taxonomy for

Table 1 Related studies

Authors	Methodology	Research Question	Domain
Hartmann et al. (2016)	Deductive study from existing BM literature	(1) Framework to analyse and compare DDBMs (2) Taxonomy of data driven business models	Data driven business models
Engelbrecht et al. (2016)	Combination of deductive and inductive approaches	To identify the dimensions of data driven business model to develop a taxonomy	Data driven business models
Schmidt, Drews, and Schirmer (2018)	Inductive study	To develop a taxonomy of Fintech business models	Fintech business models
Rizk et al. (2018)	Combination of deductive and inductive approaches	(1) What characterizes data driven digital services? (2) How can data driven digital services be clustered?	Data services
Turber, Vom Brocke, Gassmann, and Fleisch (2014)	Design science research	To develop a framework that captures specifics of IoT driven ecosystems	IoT business models

Fintech business models. However, their study used Hartmann's (Hartmann et al., 2016) framework for representing 195 Fintech business models that were further clustered to derive six clusters, when put together represent the Fintech ecosystem.

Turber et al. (2014) proposed a framework to map IoT business models on to a 3D space with dimensions representing the who, where, and why of a business model. Whilst the study represents an interesting way of mapping value creation across the ecosystem, it does not focus on capturing various intricacies associated with value creation, capture, configuration, and delivery.

Engelbrecht et al. (2016) too map data-driven business models on to a three-dimensional decision tree. The three dimensions (1) data source (user/non-user), (2) target audience (consumer/organization), and (3) technological effort (high/low) derived from a study involving "expert interviews." The decision tree is used to map 33 data-driven business models into eight categories. Like Hartmann et al. (2016), Engelbrecht et al.'s (2016) work helps us to identify the higher order dimensions central to a data-driven business model. However, unlike Hartmann et al. (2016), Engelbrecht et al. (2016) do not represent the granularity of sub-dimensions composing data-driven business models. Final, Rizk et al. (2018) study on data services focuses on service interactions between customers and service providers. The study focuses on the key activities necessary to understand data-driven digital services, as "Data Acquisition," "Data Exploitation," "Insights Utilization," and "Service Interaction" (Rizk et al., 2018).

Based on the review of related literature, we have identified the higher order dimensions of an urban data business model with which to investigate cases to derive a framework. Although various business model ontologies (Osterwalder & Pigneur, 2005), matrices (Walravens & Ballon, 2013), etc. identify various dimensions of a business model, we follow Hartmann et al. (2016) approach (which has been utilized by IS researchers (Schmidt et al., 2018)) by focusing on the most commonly cited dimensions of a business model (Hartmann et al., 2016). Hence, the higher level dimensions of the framework to explore consist of: "Key Resources," "Key Activities," "Target Customer," "Revenue Model," "Value Proposition," and "Cost Structure."

We have adopted a value proposition focused definition for the business models empirically examined for this study. For instance, a company that produces sensors to measure urban data may not qualify unless they include data management services in their offering portfolio. Thus, we define an urban data business model as a business model where urban data is central to the value proposition. This implicitly means urban data is a key resource.

Methodology

Research Design

In the UDBM context, given its nature, we argue the conventional dichotomy between the social and the technical is problematic as technical and social choices are constantly negotiated and socially constructed (Bloomfield & Vurdubakis, 1994). Therefore, also given the exploratory nature of this study, an interpretivist approach has been chosen as the primary means for addressing the RQ (Walsham, 1993). From an ontological perspective, this means that we investigate UDBM development as a complex phenomenon that is contingent on several social actors and activities. In order to capture this richness, inductive qualitative interpretive case study method was found to be suitable (Eisenhardt, Graebner, Huberman, & Miles, 2007).

Although there are numerous definitions of case studies, Yin (2003) defines the scope of a case study as follows: "a case study is an empirical inquiry that (1) investigates a contemporary phenomenon within its real-life context, especially when (2) the boundaries between phenomenon and context are not clearly evident" (Yin, 2003). Hence, case study research is a qualitative approach in which the investigator explores a bounded system (a case in a specific setting/context) over time, through detailed in-depth data collection (Orlikowski & Baroudi, 1991). A "holistic" case study is shaped by a qualitative approach focusing on a single unit of analysis, whereby an "embedded" case study involves subunits of analysis which focus on different salient aspects or levels of the case. These subunits are specific and relevant aspects for answering the overall research questions (Yin, 2003). Analysis of each subunit is completed "within-level" before "between-level" analysis occurs (Yin, 2003).

Inductive qualitative case study researchers usually combine multiple data collection methods (Yin, 2003) and keep the data collection and analysis processes flexible. Multiple sources of data were leveraged to "provide stronger substantiation of constructs" (Eisenhardt, 1989), i.e., the elements of the framework. In interpretive IS case studies, as an outside observer, Walsham (Walsham, 1995) argues that interviews are the primary data source, "since it is through this method that the researcher can best access the interpretations that participants have regarding the actions and events which have or are taking place, and the views and aspirations of themselves and other participants" (Walsham, 1995). Figure 1 below illustrates the stages of our approach. Data was thematically coded, by grouping common characteristics in relation to value creation of cases examined. We carried this out in iterative steps until all 40 cases were examined, and referred back to existing literature to best define and draw from prior literature in naming these sub-dimensions upon completion.

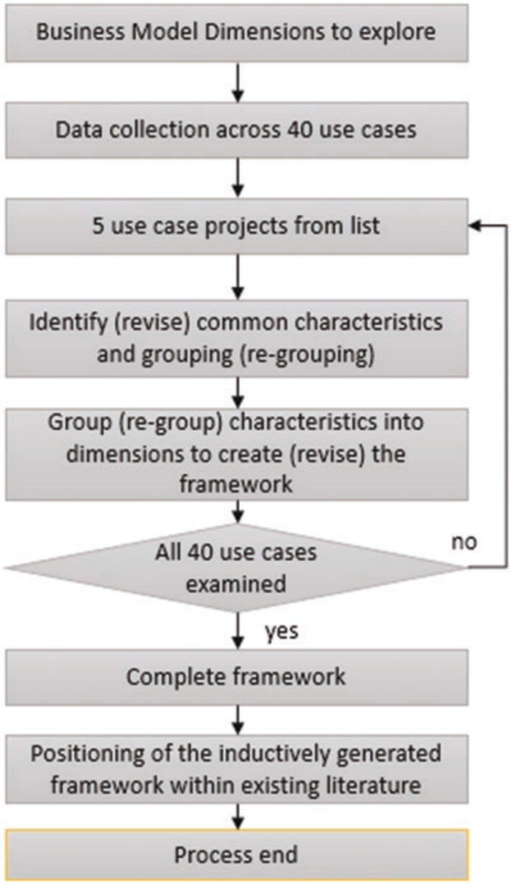

Fig. 1 Process of UDBM Framework development

Case

OrganiCity is a cross-European funding and support mechanism (including methodological guidance and IT capabilities) for experimentation of innovative urban data-driven solutions that address pressing city challenges. Originating as a H2020 research project with funding and development between 2015 and 2018, its model is an "Experimentation as a Service" (EaaS) facility. It can in some respects be envisioned as a type of federated "Living Lab" infrastructure across several European cities (e.g., London, Santander, and Aarhus) with the goal of enabling and supporting innovative urban data solutions ranging from environmental pollution monitoring to new forms of citizen engagement, etc. OrganiCity works with cities in defining city challenges to fund, with a core principle of "Co-creation" and "Real World Experimentation" in funding and supporting the defining of problems and reaching solutions. The rationale for its federated multi-city support and "Living Lab" flavored principles is to encourage the sustainability and scalability of the solutions emerging. Furthermore, it supports experimenters with a "toolkit" of both IT capabilities (centered and the OC digital platform) that can aid experimentation and privacy, ethical, and methodological guidance in carrying out experiments (see Table 2 for an overview of core features and rationale).

Between 2016 and 2018, OrganiCity organized two open calls to fund and support over 40 European "experimenters" ranging from start-ups, SMEs to grassroots movements in ideating and developing prototypes that acquire and leverage urban data to deliver a urban data-driven ecosystem, thus contributing to realizing the "smart city." Many of these experiments developed or leveraged sensor or human interface-based Internet of Things devices (IoT), mobile or web-based apps, social media, and open government data.

The first funding call was open to individuals, associations, organizations, or businesses and awarded funding of up to 60,000 euros to experiment as well as supportive guidance and resources. Evaluation of proposals for "experimentation" was by the "OrganiCity Experiment Evaluation Committee (EEC)." This committee consisted of two external experts, an OrganiCity Technical team member and one representative for each of the original cluster cities (i.e., Aarhus, London, and Santander). Proposals in both open calls were evaluated in terms of the novelty,

Table 2 Key organicity features and their rationale for sustaining and scaling

Features	Rationale for sustaining and scaling
Federation	Solutions address common challenges across European cities
Real world experimentation and co-creation	Solutions work in real world environments, and are more fit for purpose from co-creation with end-users and insight from various stakeholders
IT capabilities	Reduce time and resource barriers to prototyping
Funding and guidance	Reduce barriers to experiment and increase competencies for solution development
Brand and community	Promote credibility and synergies for and amongst experimenters

impact, and feasibility of the idea, with additional criteria of sustainability in the second open call. Furthermore, Co-creation was expected as core pillar of the experimentation design. "Experimentation" was understood in terms of planning, staffing, co-creation activities, testing, prototyping and evaluation, and reporting. Each experiment group had an appointed experiment lead, who coordinated the group and was responsible for providing feedback to OrganiCity (EU, 2017).

Data Collection

In case studying OrganiCity, we collected and analyzed various documents, reports, blogs, and publicly available information from 40 OrganiCity funded experimenters, as well as OrganiCity documents and city policy strategies. Furthermore, we analyzed in-depth interviews that took place with 30 of the 40 experimenter teams. Additionally, we interviewed city stakeholders across London ($N = 8$). The combination of this data helped us to understand both (1) OrganiCity and (2) the ecosystem of experimenters and their journey towards developing solutions. The data collected and thematically analyzed contributes to our understanding of a European urban data ecosystem and the development of urban data business models.

Upon initial analysis of the experimental cases, we identified 27 of the 40 experimenters were SME/start-ups and the rest related to NGOs, grassroots initiatives, academic projects, or multi-stakeholder partnerships. We included all cases as they could offer us insights into the data resources being leveraged, the technologies being developed and the key activities undertaken to deliver solutions. Furthermore, although some of the experiments were not-for-profit social innovation-focused organizations, they still wished to sustain the solution.

Over half of the cases (52%) related to environmental solutions (i.e., education, air quality, vegetation, sound, water, waste, and health), 12% social welfare (housing, security, disabled, and health), 12% multi-domain, 10% mobility (parking, wayfinding, and carpooling), 5% tourism, 3% urban planning, 3% Government procurement, and 3% sport. Forty-three percent had an IoT-based experimental element (most of these sensor based), whilst the remainder concerned mobile apps, web platforms, data, or innovation in hardware-based data interaction. Many relied on APIs, whilst some drew on social media platforms.

Validated Framework

In this section, we describe the validated framework derived from an analysis of the cases. We use examples from the variety of cases where necessary to illustrate inclusion of the sub-dimensions or elements, though this has been restrained due to the need for brevity. Details of all the cases can be accessed through the OrganiCity website at www.organicity.eu (EU, 2017). The framework is presented in Fig. 2.

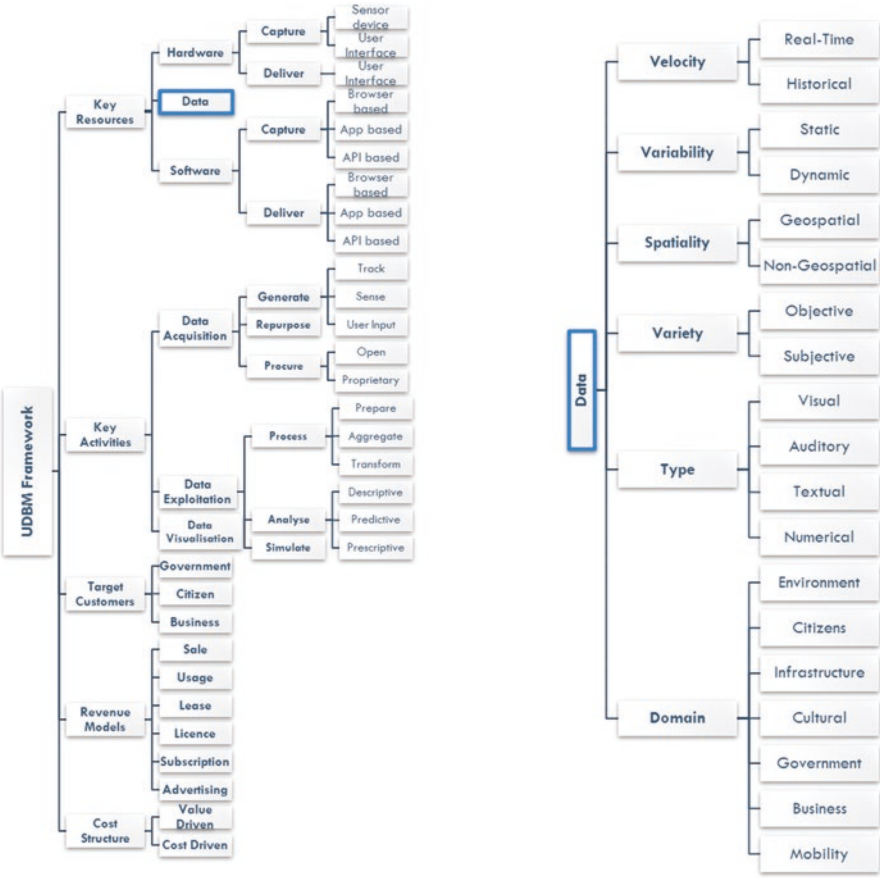

Fig. 2 Urban data business model framework

further below. What follows is a description of its dimensions and sub-dimensions, with the aid of examples where possible to aid concept definitions. Through applying the method for deriving the framework, we determined that "value proposition" will logically flow from other higher level dimensions of the framework, and thus was not included in the final framework. It should be noted that we chose to omit from the framework common elements (for example, data management and security, storage…) across cases examined that do not clearly identify value-adding elements that differentiate UDBMs.

Key Resources

Data

In terms of "Key Resources," both Engelbrecht et al. (2016) and Hartmann et al. (2016) distinguish "Data Sources" as the "Key Resource." For Hartmann et al. (2016), this is classified as "internal" and "external" data, whereby "internal" data concerns data generated through crowdsourcing, sensing or tracking, or existing sources of internal data repurposed to deliver the value proposition. "External" data is data acquired externally and further differentiated by such factors as "freely available" data, "customer provided" data, "web tracked" data, "open data," or "social media" data. On the other hand, Engelbrecht et al. (2016) differentiated data source as "User data" and "Non-User Data." However, we argue that sourcing the data is a key activity and not a key resource, whereby Hartmann et al. (2016) already captures "Data Generation" and "Data Acquisition" as an activity. Instead, we argue "Data" as the "Key Resource" should focus on the nature of the data the company generates, repurposes, or procures through various activities. The nature of the data as a key resource can then be looked at in terms of its characteristics for delivering the value proposition. For example, open data comprising of real-time geospatial pollution data may be procured from the city and overlaid with geospatial mobility data generated by IoT sensors, in order to deliver descriptive insights about the relationship between traffic and pollution.

Importantly, the characteristics of the data have a bearing on such aspects as the resources and capabilities needed to leverage the data, as well as wider socio-political factors on its collection and use. For example, generating real-time data may require greater storage, could have higher telecommunication costs, additional processing and analyzing capability and may not be suitable to generate through low powered sensor devices. Auditory or visual data may involve additional privacy and security considerations, whilst open data may have sustainability concerns if a business is reliant on data's updating and longevity (Maccani, Donnellan, & Helfert, 2015). In all we found data could be characterized according to "velocity," whether "real-time" streaming data or near "real-time" data (data sensed and uploaded very frequently), and "historical" data, i.e., all other data. For example, several experiments provided near "real-time" data by using low powered sensors, rather than "real-time" streaming. The "variability" of data was also a consideration, whereby "static" data refers to data unlikely to change over time. For example, data on the location of assets in the city. "Variability" also relates to "dynamic" data, which is data that is likely to change and thus requires frequent measurement. For example, Spend network drew on both "static" and "dynamic" open data to offer insights into city councils. Data may also have "variety" in term of being "subjective" or "objective." "Subjective" data refers to "user-input" based data such as with the case of "Tranquil City" where citizens identified tranquil spaces in the city, or "objective" data such as "iCycle" (IoTee Lab) which use IoT to measure the fill levels of bottle banks. The type of data, "Auditory," "Textual," "Visual," or "Numerical," was also an important distinction in the proposed solution offered, and the resources and activities needed to capture the data and deliver the solution. For example, citizens "textual" annotation of IoT-sensed "numerical" data is used by "Camon" to aggregate "objective" and "subjective" air quality levels.

Finally, we distinguish the "Domain" of urban data in terms of "Environment," "Citizens," "Cultural," "Business," "Mobility," "Infrastructure," and "Government." For example, "Infrastructure" data relates to urban spaces and places and facilities in the city including buildings, parks, power supplies. This may relate to unused or vacant spaces in the city, such as is the solution from the social enterprise, "Space Engagers." "Environmental" data refers to data about the natural environment of the city such as air and water, wildlife, or even soil and grass such as the case of experimenters "Green Roof Monitoring." "Citizens" data refers to any data about citizens, often communicated by citizens. For example, "Data on Site" proposes new ways for citizens to interact and submit data about the city. "Government" data relates to data about city governance and council activities and processes, as was the case for "Spend Network" who drew on open data to offer insight into public sector sending. "Cultural" data refers to data about history, events, social activities, etc. in the city, such as for "Walks in the City" developed a map to recommend places and spaces' for senior walkers. Finally, "Mobility" relates to traffic, travel and wayfinding-related data in the urban context. For example, "Traffic controlled by air quality," which aimed to improve movement of traffic to improve air quality levels.

Hardware and Software

Not only will the nature of data needed to deliver the value proposition have implications for resources and activities of an organization, but the hardware and software resources suggest the type of value proposition an organization offers, whether in capturing data and delivering data or insights. We found these differed across cases examined warranting the inclusion of these sub-dimensions. For example, to offer a city and its citizens "Sensing as a Service" of real-time air pollution levels, an organization may require: (1) installing IoT (Internet of Things) "hardware" "sensors" on assets across the city in order to "capture" data, (2) a "hardware" "user interface" combined with "app-based" "software" installed in public places in order to "deliver" "descriptive" insights to citizens, and (3) "browser-based" "software" in order to "deliver" "predictive" insights to city officials.

Thus, we further differentiate "Key Resources" in terms of "hardware" and "software" specifically needed to "capture" data and "deliver" data and/or insights through the value proposition, though acknowledging that hardware and software resources needed by organizations go beyond these value-adding elements. Engelbrecht et al. (2016) identify "technological effort required" in distinguishing data-driven business models, this study proposes both "Key Resources" (in terms of hardware and software) and Key Activities (e.g., preparing data to prescriptive insights and visualization) and elucidates technological effort in how urban data business models are identified. Therefore, in terms of hardware, a "sensor device" such as an IoT device may be used to capture "objective" noise levels across the city, such as with the Belgium organization, "Sensifai." A "user interface" may be installed for the public to capture "subjective" views of sound levels by citizens, and then aggregated, analyzed, and visualized in delivering prescriptive recommendations to city officials through a hardware "user interface," and delivered to citizens through an "app-based" mobile software program. For example, "Research X Design" (Data on Site) developed a toolkit solution for public participation, whereby voting hardware and software devices are installed on city assets. "Empati" designed mobile flower pot style interfaces to place in city parks to gather subjective feelings of citizens.

Key Activities

Following Rizk et al. (2018), we propose that "Data Acquisition" is a key activity whereby an organization draws on: (1) hardware and/or software resources such as sensors, trackers, or "user input" interfaces to "generate" data, (2) software resources including APIs to "procure" either "open" or "proprietary" data, and/or (3) existing data resources internal to the organization, i.e., "Repurpose." In terms of "sense," we refer to Internet of Things (IoT) devices installed in a town/city, or data captured by sensors on a citizen's smartphone, e.g., GPS. By "Trackers," we refer to algorithms and cookies that allow an organization to capture web-based data such as social media data or website data including user online activities. By "user input," we refer to data entered by citizens through an interface device such as voice or text. We further distinguish, "Data Exploitation" (Rizk et al., 2018) and "Data Visualization" as sub-dimensions of "Key Activities." "Data Exploitation" aims to create additional value from the data through "processing," "analyzing," and "simulating" data. By "processing" we mean "preparing" (cleaning, structuring, etc.), "aggregating" (combining datasets or different types of datasets), and/or "transforming"(converting or modifying) data (Fayyad, Piatetsky-Shapiro, & Smyth, 1996), which is a lower degree of data exploitation and abstraction. "Analysis" and "Simulation" are a higher level of "Data Exploitation" aiming at extracting knowledge, i.e., insights (Rizk et al., 2018). These can be classified as "descriptive" (summarize or report patterns and relationships), "predictive" (analyzes data to make "predictive descriptions" or "predictive foresight"), or "prescriptive" (identifies options, suggests or recommends actions) insights (Hartmann et al., 2016). In terms of "predictive" analysis, we observed experiments which leverage AI and NLP (National Language Processing) to predict the characteristics of data, i.e., what we term "predictive description." For example, predicting with high probability that a sound belongs to a species of bird, or an image contains a certain number of people. This level of data exploitation exceeds that of descriptive analysis using more traditional methods. "Predictive foresight" on the other hand refers to predicting future states/events. For example, predicting cost savings, when bins will become full, or when additional policing resources will be needed. "Simulation" refers to the recreation of a complex system to run various "what if" scenarios and assess the possible behaviors of an actual system. In the context of digital innovation, virtual modeling, or simulation is becoming an ever more attractive value proposition (OECD, 2019).

Finally, "Data Visualization" (Elgendy & Elragal, 2014) concerns the activity with which the exploited data may be presented to the end use. Converting complex information into visually engaging charts and images is a very niche value proposition few firms specialize in. Usually, firms couple the visualization capability with other key activities such as analytics rather than offering it standalone. "Edinburgh CitySounds" is one such experiment selected for the second phase of OrganiCity. The experiment captures sounds by installing "auditory" data "sensor" devices (AASs) across the city. These AASs will capture short clips of ultrasonic and audible noises of bats, birds and other wildlife, traffic, and human activity in real time. These sounds in turn are aggregated with other data sets such as light, temperature, humidity, pollution to answer questions pertaining to the impact of human activity on animal behavior, changes in human/animal behavior with exogenous variables. It is imperative for Edinburgh CitySounds to develop visual standards to represent these seemingly unstructured, inconsistent, incoherent data sets, in doing so greatly enhance the utility of the final offering.

Target Customers

The basic premise of an OrganiCity experiment is to tackle an urban challenge. Consequently, the experimenters would look to deliver to any one or more stakeholders in an urban setting. Stakeholders such as citizens, other businesses, and city councils/governmental organizations could all be the key customers for experimenters. Moreover, unlike traditional businesses that mostly focus on one customer segment at a time, business models in an urban setting have a more complex interwoven nature with various stakeholders. Often seen are experimenters that deal with multiple customer segments at the same time. This is also seen as a way of achieving larger market needed for eventual viability of the business model.

Green roof monitoring, an Oslo-based experiment, is an example for operating in multiple target customer segments. It offers multisensorial monitoring of vegetation for citizens, businesses, and the municipality. Another experimenter, "Leapcraft," a sensing platform to measure air quality has the city council as a target customer, whilst developing citizen dashboards to communicate insights from air pollution measurements.

Revenue Models

As discussed earlier, most of these experimenters are still in the process of discovering stable revenue streams. Some of these experiments in their current state only lend support to the experimenting firm's other business units without generating any revenues themselves. Moreover, revenue models, like other business model components, are prone to frequent changes. We have observed six different revenue models adopted or planned by experimenters to extract value from their offerings: asset sale, usage fee, leasing, licensing, subscription fee and advertising fee. For instance, "Wayfindr" provides its customers consultation for setting up audio navigation services and charges a (usage) fee. Whilst, "AirPublic" provides insights on the air quality to the city councils that subscribe to its services. FSTR licenses the use of its carpooling application to businesses which in turn make it available for their employees.

Further into each of these revenue models is the actual pricing mechanism for services and/or products. Osterwalder's (2004) three broad characterizations of pricing mechanisms—fixed, differential, and market based—have been used by experimenters. Predictably, most of the experimenters that deal in the B2B and B2G segments, owing to their relative lack of bargaining power whilst dealing with larger businesses, have been playing the role of price taker rather than price maker. It has also been observed that only a handful of experimenters with IP protected assets were able to take the lead and set prices.

Cost Structure

On the continuum of value driven to cost driven, we have observed that most of the OrganiCity experimenters are aligned closer to value driven extreme. It could be due to an emphasis on innovative and novel solutions rather than cost-effective solutions by the reviewers. Having said that, there are some experimenters who emphasized delivering solutions in a cost-effective way in their value proposition.

Empati and Leapcraft are examples of cost-driven experimenters. Each one of them deliver solutions seeking to capture a market by offering a lower cost solution. For example, Leapcraft seeks to lower the cost of measuring air pollution and increase spread by developing mobile-based air quality sensors that traverse the city on vehicles. Besides, OrganiCity is created as a platform to facilitate experimentation. Facilitating experimentation includes minimizing overheads needed to run these experiments. By providing technical expertise, a legal framework and access to data sets, the platform has provided a frictionless environment for innovation. However, since all the experimenters have common access to these facilities, we have not delved deep into these provisions/factors as they do not distinguish between experiments.

Application of the Framework

In this section, we illustrate the application of the framework by describing common types of UDBM observed, along with case examples from OrganiCity to illustrate each. We have chosen six experiments that represent a heterogeneous application of the framework in terms of differing activities, resources, cost structure, revenue stream and target customers. It should be noted that some cases examined operate under more than one business model, i.e., a portfolio of business models to support multiple value propositions, whilst others integrate together aspects of the business models presented. Thus, the examples given are not stringent nor are they necessarily static and can evolve over time. For example, they may offer sensing and analytics as a product and/or a service arrangement.

"Sensing as a Service" Model

The "sensing as a service" business model typically focuses on the deployment and maintenance of hardware-based sensor devices along with cloud storage and a software-based interface for delivering descriptive insights to customers under a leasing arrangement. In some cases, sensor deployment is offered as a product, with a maintenance service provided, whilst the value-adding cloud storage, analytics and visualization of data is offered as a service via an app or browser-based software interface. The service is typically B2G, and some value-adding predictive and/or prescriptive insights may also be added.

Example: Air Pollution Data

Many cities struggle with the cost of having granularity, accuracy and insight of environmental data in their cities. For example, cost raises challenges for achieving sufficient granularity of pollution monitoring to street level, whilst achieving valid measurement. One of the approaches to addressing these challenges is to implement mobile mounted sensing at street level to increase depth of coverage. The Danish-based company Leapcraft has developed a Sensing as a Service implementation for air pollution monitoring. They can include such aspects as techniques and calibration for sensor deployment and maintenance. As experimenters with OrganiCity, they prototyped and trialled lower cost mobile mounted air pollution sensor devices to increase the granularity of air pollution sensing in the city. Key activities focus on (1) Generating environmental sensor data and (2) Procuring environmental open data in order to calibrate and validate their sensor data. Leapcraft generates and exploits near real-time numerical geospatial objective environmental data. They hope to enrich insights from sensor data by procuring and exploiting further sources of open data. The offering emphasizes a cost-driven proposition, in terms of the

<table>
<tr><td colspan="2">Cost Structure:
Cost (Value) driven</td><td colspan="2">Target Customers:
B2G – B2B</td><td colspan="2">Revenue Models:
Lease - Subscription</td></tr>
<tr><td colspan="3">Key Activities:
- Generate sensor data
- Procure environmental open data
Descriptive & predictive insights from transformed data
- Visualisations of data insights</td><td colspan="3">Key Resources:
- Sensor based Hardware capture device
- App based Software Platform delivery
- (Near Real-time & historic geospatial, objective, numerical) environmental data.</td></tr>
<tr><td colspan="6">Value Proposition: Sensing as a Service</td></tr>
</table>

Fig. 3 Sensing as a service

lower cost of sensors and reduced number of deployments, though they also offer value-adding cloud storage and analysis and visualization. See figure 3 for an overview.

Their value proposition is to offer the customers both hardware sensor capture devices and app-based software (dashboard) to deliver customers analytics and visualization capabilities for descriptive and predictive insights of environmental data. Their customers are either Business to Business (B2B) or Business to Government (B2G), and they offer CKAN pre-integration of data to cities as part of the B2G offering. The solution includes cloud storage capability whereby historical environmental data generated and procured is offered to customers for analysis and insight.

"Prescriptive Insights as Product" Model

"Prescriptive insights as product" concerns business models where data is generated and/or procured to provide prescriptive insights for the customer based on the gathered data evidence. Thus, the core value generated is prescriptive insights such as recommendations or a suggested course of action that typically results in cost and/or time savings for the customer. The provider demonstrates competence in AI/machine learning for optimizing recommendations and may include sensing as a product/service as part of its offering. For example, wayfinding app solutions that procure open data to offer wayfinding advice to citizens traversing the city. Such wayfinding apps rely on acquiring and processing data, including aggregating and transforming open data in order to carry out prescriptive analysis to deliver optimal routing. Models observed typically fall into B2G or B2C.

Example: Waste Fill Data

In the context of smaller urban municipalities, the deployment of sensor technology-based bins can be commercially prohibitive, and lower cost solutions are needed. Working with OrganiCity, Iotee Lab (WasteHero) developed and tested a technique and technology for retrofitting existing bins with ultrasound-based low-powered IoT sensors that can connect across LoRa, Sigfox, or NB-IoT networks. The organization offers hardware sensor capture devices and a browser-based platform to deliver customers both descriptive, predictive, and prescriptive analytics and visualization capability for bin fill measurement. These include prescriptive bin collection route planning and predictive foresight in terms of cost savings. As experimenters with OrganiCity, they co-created with citizens to develop a browser-based citizen front end also. The solution is oriented towards the B2G market and aligns closer to a value-driven model, in terms of the benefits of the solution, though also can be seen as cost driven in terms of lower cost of deployment. In this regard, the sensors are offered as turnkey product solution, whereby training is offered for customer employees to install the sensors. They are exploring additional revenue models such as lease and Performance based Payment (PBA). Hardware sensors generate near real-time geospatial dynamic objective environmental data and static geospatial objective infrastructure data. To enhance their offering in the future, procuring open data can improve the predictive and prescriptive analytical insights of bin collection. In other words, festivities, events, and other contextual data could enhance their offering. Refer to figure 4 below for an overview.

"Analytics as a Service" Model

"Analytics as a service" business models focus on delivering software-based interfaces that deliver value-driven insights from procuring and effectively exploiting open and proprietary data. This model emphasizes value-adding activities of processing data (i.e., preparing, aggregating, transforming), as well as analytic and

<table>
<tr><td>Cost Structure:
Cost-Value driven</td><td colspan="2">Target Customers:
B2G</td><td>Revenue Models:
Sale</td></tr>
<tr><td colspan="2">Key Activities:
- Generate sensor data
- Descriptive, predictive & prescriptive insights from transformed data
- Visualisations of data insights</td><td colspan="2">Key Resources:
1. - Sensor based Hardware capture device
2. - Browser based platform delivery
3. - (Near Real-time & historic</td></tr>
<tr><td colspan="4">Value Proposition: Prescriptive Insights as a Product</td></tr>
</table>

Fig. 4 Prescriptive insights as a product

visualizing capabilities that give customers value-adding insights. This business model typically relies on procured data and is thus heavily dependent on sustainable partners and/or Service Level Agreements (SLA) from open data to remain viable. Offerings observed include B2G, B2B and B2C.

Example: Open Government Expenditure Data

Leveraging an increasing quest for open government and transparency, Spend Network delivered a browser-based interface to display and analyze public expenditure data. A value-driven cost structure and subscription-based Freemium revenue model has been established, whereby aggregated spending information is available for free through the website, and users are charged through subscription for additional features. These include: (1) the provision of procured and prepared open government data—to enable further independent analysis and (2) the provision of descriptive as well as predictive analysis/insights from aggregated government expenditure data including information about both supplier and buyer landscapes. An overview is given in figure 5 below.

Business and government sectors are the target customer segment. Spend Network procures objective historical open data to extrapolate trends. This consists of both static and dynamic open data, and textual and numerical open data. Geospatial data is not currently part of its offering.

Key activities undertaken as part of this value offering include Data Acquisition and specifically procurement of open government data, data exploitation and visualization. Whilst the solution is described as the provision of "raw data," in fact processes of data cleaning—i.e., prepare—and some aggregation are conducted on the data initially procured. Extensive manual data cleansing and cleaning processes ensure sufficient quality and accuracy. These are in place to address the challenge of obtaining relevant and accurate data in a situation where contracts or any other form of agreement to ensure provision of data are lacking.

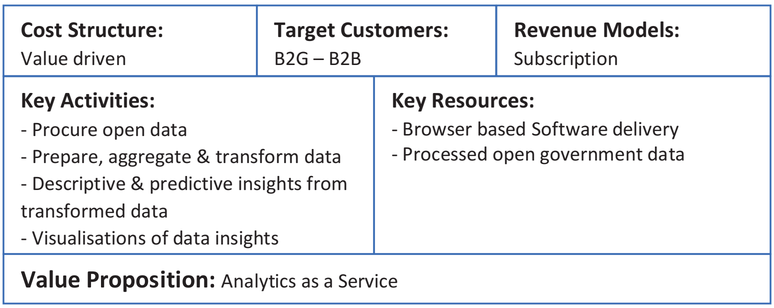

Fig. 5 Analytics as a service

"Recognition as a Service" Model

The "recognition as a service" offering centers around innovation in Artificial Intelligence (AI) capability to extract, identify, and in some cases understand the characteristics inherent in generated and/or procured data. These services may range from computer vision (e.g., identification and understanding of characteristics inherent in captured images or videos) to sound recognition (e.g., identification and understanding of characteristics inherent in audio recordings) and thus rely on superior resources and capabilities in data science techniques. Common examples include video sensors that count vehicles, people, etc. and audio sensors that recognize types of sounds. These organizations focus on analysis that is "predictive description," and revenue models observed are typically via sale, subscription, or advertising, and sensor deployment and maintenance may form an integral part of the offering.

Example: Noise Pollution Data

Increasingly, noise pollution is seen as a key factor impacting the quality of life in urban environments. It is therefore vital for the city authorities to manage and control noise to make cities more livable. One of the bottlenecks, from a technological standpoint, is to accurately measure the noise levels in real time across the city and to isolate the sources of noise to arrive at actionable insights. Sensifai, a Brussels-based OrganiCity experiment, set out to address these challenges. With support from OrganiCity, they prototyped solutions that capture high-quality, near real-time geospatial audio data by using auditory and geolocation sensors fitted to moving vehicles. Sensifai generates sensor-based data via a hardware capturing sensor device. This data is then transformed and analyzed using artificial intelligence enabled deep learning methods to extract subjective (types of noise) "predictive description" and objective (noise level and location) descriptive insights on noise. These insights are visualized onto a noise map which can be accessed by various stakeholders including citizens and delivered through a public browser-based interface. Thus, the service is value driven in terms of visualizing descriptive and predictive insights, both objective and subjective in nature. The offering is cost effective in terms of coverage and granularity by traversing the city with mobile mounted sensors. See figure 6 for an overview.

Although their initial target customer segments are citizens (B2C) and the government (B2G), they hope to eventually offer services to businesses (B2B), primarily real estate agencies, to identify tranquil spaces in the city of benefit to client advice, pricing and planning. In its current form, advertising on the website drive their revenues. They plan to be able to validate the offering to an extent where businesses approach them to purchase deeper insights into the city's noise landscape.

<table>
<tr><td colspan="2">Cost Structure:
Value (cost) driven</td><td colspan="2">Target Customers:
B2G – B2B – B2C</td><td colspan="2">Revenue Models:
Advertising – (Sale)</td></tr>
<tr><td colspan="3">Key Activities:
- Generate audio sensor data
- Prepare, process, transform data via AI processing methods.
-Visualize the sound database as a descriptive noise map.</td><td colspan="3">Key Resources:
- Sensor Capture devices
- AI based sound processing algorithms
- Processed (Real-time & historic, geospatial, dynamic, objective & subjective audio) environmental data</td></tr>
<tr><td colspan="6">Value Proposition: Recognition as a Service</td></tr>
</table>

Fig. 6 Recognition as a service

"Automated Service Interaction" Model

The "automated service interaction" business model focuses on exploiting conversational AI and rule-based dialog technology, including natural language processing (NLP), and data ontologies to offer automated conversational agents in fulfilling information service provision. Key activities involve acquiring and processing citizen data in order to offer descriptive and prescriptive analytical insights of procured data to citizens. This may entail developing rule-based dialog flows and/or NLP to match citizen requests with procured data. Communication may be either textual or verbal via speech recognition. The customer is B2B or B2G, and many offerings typically rely on partners to deliver AI and rule-based dialog capability.

Example: Open Urban Data

An important consideration in the delivery and uptake of smart city services include the digital divide and convenience factors across various cohorts of citizens. This necessitates that governments facilitate easy and intuitive service delivery interfaces. TalkingCity, an OrganiCity experiment in the city of Aarhus, prototyped a platform for conversational style information service provision. These "Chatbots" use natural language processing techniques to communicate and understand citizen requests. TalkingCity acquires data through both procuring open data via API based software and generating user-input data via app/browser-based software. In terms of procuring open data, they connect to various open data platforms to extract data required to answer citizen queries. This consists of ingesting citizen queries, recognizing intent, connecting with open data platforms and generating a response back in natural language. TalkingCity procures all kinds of open data ranging from real time to historic, static to dynamic, objective to subjective, and environmental to governmental. Thus, a key activity is preparing, transforming, and exploiting data to deliver descriptive and prescriptive insights based on queries. Software capture of user-input data is via app-based or browser-based (third party) interface and delivered via the same medium. Thus, these "Chatbots" work over popular existing interaction channels such as Facebook, Whatsapp, Telegram, and Slack. An overview is shown in figure 7.

Cost Structure:
Value driven

Target Customers:
B2G – B2B

Revenue Models:
Sale and Usage

Key Activities:
- Procuring Open Data
- Generating User Input Data
- Exploiting data using NLP for Descriptive/Prescriptive insight

Key Resources:
- Algorithms to Natural Language Process (NLP)
- APIs to enable cross platform intergration
- Dynamic subjective textual citizen data

Value Proposition: Automated Service Interaction

Fig. 7 Automated service interaction

TalkingCity hopes to build the technology and as it matures, engages with various service providers that are both governmental and commercial. By such engagements, they hope to have access to revenue streams such as one-time setup fees, recurrent fees from platform hosting services and other support and training activities. The target customers include municipalities, city councils (B2G) and private businesses (B2C).

“Crowdsourcing Community Platform” Model

“Crowdsourcing community platform” models rely on citizen user input and/or citizen’s smartphone sensors to acquire various types of urban data. The focus is typically on galvanizing citizens to generate urban data around specific issues, topics or challenges. The offering is via app and/or browser-based software and relies on network effects or a critical mass of users to add value and sustain. In some cases, citizen derived data is procured via tracking from social media sites in order to visualize aggregated data (e.g., hash tagging tranquil places in the city) on an app or browser-based interface. The revenue model is typically via B2G sale or B2C advertising and/or public funding.

Example: Infrastructure Data

Digital technologies have begun to be leveraged for preserving the cultural heritage of cities and promoting urban renewal efforts. This in concert with community-driven efforts can promote democratization in producing the city, whilst reducing cost of data gathering through crowdsourcing initiatives. The social enterprise and OrganiCity experimenter, “Space Engagers” has a mission to promote community renewal through combing citizens’ crowdsourcing, mobile platform technology, and open data. Space Engagers, through its engagement in OrganiCity, developed its community engagement tool, to enable and support communities to generate urban data around issues such as vacant places and spaces. The experience in OrganiCity also enabled Space Engagers to scale the application across multiple urban environments. Space Engagers leverages a software app-based interface to capture and deliver data. Geospatial Visual Infrastructure data (images) and textual subjective and objective data (text comments) are generated through user input, whilst mapping data is procured as open data. Thus, the main source of data is obtained through crowdsourcing. As a result of the key activities of generating and aggregating data, the app features an interactive map (open geospatial visual data) to visualize pictures and comments on a specific area of the city. This in turn enables other participants to discuss potential community projects and to interact on possible ideas for addressing the challenges posted in the original upload. Examples of successful projects so far include several community-led urban regeneration initiatives as well as mechanisms through which governments can take more informed and citizens-centric decisions.

The cost structure can be viewed as value driven in terms of new modes of gathering urban data through tailored crowdsourcing-based apps. The target customer is B2G in terms of this social enterprise empowering citizens directly in engaging with urban issues. The development of the app has been ensured through revenue from public funding initiatives and does not rely on a typical revenue model of advertising, sale, or subscription. See figure 8 for an overview.

Conclusion and Future Work

This study has presented a framework of urban data business models, defined as a business model where urban data is the central to the value proposition. We analyzed 40 urban data focused experimental cases under the umbrella of the EU H2020 OrganiCity to inductively derive the framework. The framework composes five higher level dimensions based on the six dimensions we identified from the literature review. Through the exercise of developing the framework, we determined that "Value Proposition" will logically flow from other higher level dimensions of the

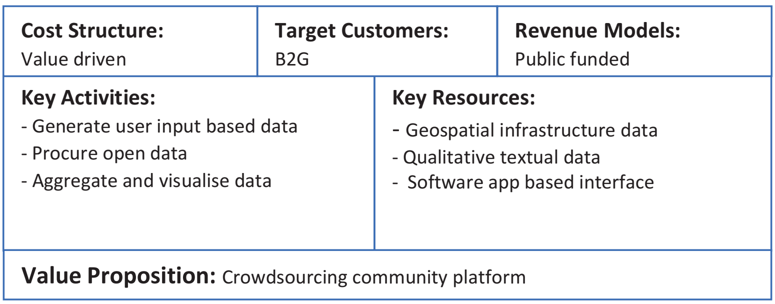

Fig. 8 Crowdsourcing community platform

framework and thus was not included in the final framework. In other words, "data" or resulting "knowledge" or "insight" is reflected through the activities a business undertakes to exploit and visualize the data, and thus captured through the framework. This also avoids the problem of multicollinearity which would affect subsequent clustering of business model types when applying the framework.

Through the analysis of cases, we determined that "Key Resources" should compose of both urban data capturing and delivering hardware and software, as these were a core offering of many of the cases we explored. Comparing the existing literature, this is implicitly referred to by Rizk et al. (2018) as product or application-based "Service Interaction," as "Technological effort" by Engelbrecht et al. (2016) and by Hartmann et al. (2016) through sub-dimensions of "Data Sources" and "Data Generation."

As a result of the literature review, the variables in our framework have carefully been identified to avoid inter variable redundancies, thereby making the framework amenable for developing a taxonomy of urban data business models. For example, we argue that sourcing the data is a key activity, and not a key resource, whereby Hartmann et al. (2016) already captures "Data Generation" and "Data Acquisition" as an activity in addition to capturing these through the "key sources" that he distinguishes.

In order to illustrate the applicability of the framework, we have selected six heterogeneous cases from OrganiCity to illustrate differing urban data business models. The next stage of the study will be to apply the framework to all OrganiCity supported cases to cluster and classify business models types. We furthermore plan to apply the framework to existing businesses which have already established a sustainable business model to identify trends within the industry.

As touched on in the introduction, we believe the framework can be useful for researchers as a common language and analytical lens in (1) understanding challenges across the value network in developing urban data business models, (2) identifying opportunities for value propositions and related urban data business model combinations, and (3) substantiating the types of urban data business models. Furthermore, the framework may be drawn on by practitioners in assessing proposals for funding and support, including viability in the context of the funding and the challenges with which to develop a solution.

This work was supported with funding from Science Foundation Ireland grant 13/RC/2094 and Intel Labs Europe.

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Towards Smart Governance: Insights from Assessing ICT-Enabled Social Innovation in Europe

Gianluca Misuraca, Fiorenza Lipparini, and Giulio Pasi

Abstract Building on results of the research on 'ICT-Enabled Social Innovation to support the implementation of the Social Investment Package' (IESI), this chapter aims to contribute to the debate on the development of new smart governance models in the social innovation domain, leveraging on the potential of digital technologies for enhancing collaborative governance and civic engagement. In this perspective, after discussing the approach followed to conceptualise ICT-enabled social innovation through literature review and analysis of initiatives gathered in sequential rounds of mapping, the chapter provides insights from the analysis of the European landscape and the policy debate around social innovation and policy reforms. In particular, the evidence gathered shows that systemic initiatives are mainly happening at the local level, and public authorities have a key role acting as catalysers and enablers of social innovation and digital governance. Involving beneficiaries of specific services is often a key driver to improve the ability of cooperation of stakeholders and to expand the collaboration with the wider local community, with particular importance for 'smart city' governance. Innovative public–private collaborative practices emerge to strengthen the modernisation of the European social agenda, with public actors acting as orchestrators and amplifiers of innovation and resilience into a varied array of welfare policies and governance models. The results of the analysis have clear implications on the smart governance and smart cities debate at both academic and policy level. First of all, it is clear that ICT-enabled social innovation has a strong potential to empower citizens' participation in the life of a community and thus enhance civic engagement which can result into innovative collaborative governance. At the same time, leveraging on the capacities of digital technologies, new services can be designed and delivered providing personalised solutions to improve conditions of disadvantaged groups and help shape a better community's life.

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_10

Keywords Governance · Technology · Social innovation · Europe

Introduction

This chapter contributes to the debate on the development of new smart governance models in the social innovation domain leveraging on the potential of digital technologies for enhancing collaborative governance and civic engagement.[1]

The chapter builds on the outcomes of the research project on 'ICT-Enabled Social Innovation to support the implementation of the Social Investment Package' (IESI).[2] The rationale of IESI was to assess the contribution of ICT-enabled social innovation to promote social policy reforms, based on the analysis of a broad collection of well documented initiatives, which could be adjusted, scaled, and replicated across Europe. In addition, the IESI project set out to build a toolbox, composed of the initiatives database and a methodological framework to assess their social and economic impact, to help interested parties in designing, implementing, and evaluating other ICT-enabled social innovation initiatives across Europe.

The work that has been carried out under the IESI research project since 2014 is particularly relevant today in light of the development on the ground of the EU Pillar of Social Rights within the framework of the next EU Multiannual Financial Framework (MFF) and the implementation of structural reforms and investments, especially at city level. The Social Investment Package in fact was launched by the Commission to help 'reorienting Member States' policies towards social investment where needed, with a view to ensuring the adequacy and sustainability of social systems (…)' (European Commission, 2013). While acknowledging the key role played in Europe by welfare systems in ensuring inclusive growth, as well as their stabilisation function in time of financial and economic hardship, the Commission also recognised that an extra effort was required to meet citizens' needs while ensuring fiscal sustainability and increased competitiveness. In order to combine social cohesion and competitiveness of the Member States, the Commission promoted investments in a wide range of social services and social innovation initiatives contributing to address new social needs, to balance care responsibilities, to create new jobs, and to strengthen labour productivity.

Concerning the EU Pillar of Social Rights, in his first State of the Union, President Juncker declared that "*in order to foster the convergence process within*

[1] According to Adler and Gogging (2005), "civic engagement refers to the ways in which citizens participate in the life of a community in order to improve conditions for others or to help shape community's future".

[2] In 2014 the European Commission's Joint Research Centre, in partnership with the Directorate General for Employment, Social Affairs and Inclusion, engaged in a 4-years research project on "ICT-enabled Social Innovation to support the Implementation of the Social Investment Package" (IESI). See https://ec.europa.eu/jrc/en/iesi

the Eurozone, it was necessary to strengthen the social dimension of the Economic and Monetary Union, creating a reference framework 'to screen the employment and social performance of participating Member States'" (Juncker, 2015) and drive the necessary reforms at national level.

This position was then reinforced in the Commission's proposal for the 2021–2027 EU budget, which '*has a vital role to play in delivering on the promises made by Leaders at the Gothenburg Social Summit in November 2017. This means strengthening the social dimension of the Union, including through the full implementation of the European Pillar of Social Rights. Within Cohesion Policy, a strengthened and restructured European Social Fund will amount to around EUR 100 billion over the period, representing a share of about 27% of cohesion expenditure*'.

The ESF will be particularly focussed on youth employment, up and re-skilling of workers, social inclusion, and poverty reduction. Importantly, links between the European Structural and Investment Funds (ESIFs) and the European Semester process will be reinforced, and investment guidance will be provided by the Commission together with the annual Country-Specific Recommendations. A new 25 billion Reform Support Programme will also be established to provide technical and financial support for key reforms at national level, identified as part of the European Semester. Links with the EU Research and Innovation programme, which will be strongly mission driven, will also be reinforced, while funds—both in the form of financial instruments and grant—to accelerate the ongoing digital transformation process while tackling its potential negative externalities will be increased.

In this respect, it is important to notice how, beside Horizon Funding and the Connecting Europe Facility, a new 9.2 billion EUR Digital Europe Programme will be created to help complete the Digital Single Market. The new instrument will support strategic projects in areas such as artificial intelligence, supercomputers, cybersecurity, and industrial digitisation, as well as digital skills. The Communication on the EU Budget acknowledges the deep influence that the digital revolution is having not only on our economy but also on our 'societies, jobs and careers, as well as our education and welfare systems'.

This integrated approach to economic and social reform is mirrored by the InvestEU facility which will succeed to the previous Juncker Investment Plan, aiming at mobilising over 650 billion EUR of additional investment across Europe with an EU contribution of EUR 15.2 billion. Building on the success of the EFSI, the new fund will absorb and streamline all the current financial instruments under four main headlines, i.e. Sustainable Infrastructure, Research and Innovation, Social, Skills and Human Capital Investment and Small and Medium Enterprises (SMEs).

The main goal of this chapter is to provide insights from the analysis of the European landscape of ICT-enabled social Innovation and the policy debate around social innovation policy reforms, to contribute to the discussion on smart governance mechanisms and especially at local and city level.

For this purpose, the remainder of this chapter is structured as follows. Section "Methodology" presents the methodology followed to conceptualise the phenomenon under investigation through literature review and analysis of initiatives gathered in sequential rounds of mapping. Section "Results" discussed some of the results providing a comparative and chronological analysis of the typical ICT-enabled social innovation initiatives, and a focus on the analysis of the last mapping exercise, where the link between social innovation and resilience has been looked at with particular attention. The final section offers conclusions by first testing the initial research hypotheses and then outlining the main insight emerged, in terms of future research and implications for policy in the realm of smart governance.

Methodology

Definitions and Approach

At the core of the IESI project analysis stands the definition of ICT-enabled social innovation, which was agreed upon in 2014 and maintained throughout the project life-spam. This is defined as: *A new configuration or combination of social practices providing new or better answers to social protection system challenges and needs of individuals throughout their lives, which emerges from the innovative use of Information and Communication Technologies (ICTs) to establish new relationships or strengthen collaborations among stakeholders and foster open processes of co-creation and/or re-allocation of public value.* (Misuraca, Colombo, Carretero, Bacigalupo, & Radescu, 2015).

ICT-enabled social innovation is therefore a crucial facilitating element for better integration of services across sectoral and organisational boundaries, fostering cost-effectiveness, and personalisation of services.

The IESI project consisted in the creation of one of the largest existing collection of the most significant initiatives, services, and products applying ICT to social innovation in Europe. Since 2014, more than 800 cases were collected and documented in the IESI inventory, out of which 400 were mapped following the IESI conceptual and analytical framework, discussed in more details below. Importantly, initiatives to be included in the IESI mapping were selected not only on the basis of their policy relevance and on the fact that they presented elements of ICT-enabled social innovation but also because they showed some proof of evidence of impact achieved. Proof of evidence was deemed necessary to facilitate the identification of key drivers and enabling factors to successfully innovate social policies, while highlighting opportunities for replication and scaling, as well as potential 'transferability' across different welfare models and governance systems.

As showed in the Fig. 1 below, the methodology is composed of two main strands:

1. Literature review aimed at designing the conceptual and analytical framework, replicated two times during the research project.
2. Mapping and analysis of the initiatives, replicated three times during the research project.

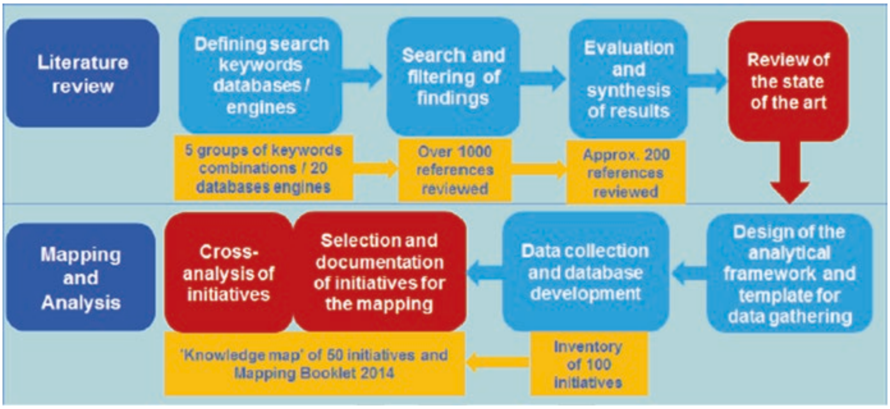

Fig. 1 Methodological approach. (Source: Misuraca et al., 2015)

According to an incremental approach, the findings of each round of mapping informed changes to the conceptual and analytical framework, reviewed and enriched with new items as the research progressed. The consolidated analysis allowed to further validate the IESI conceptual framework by applying it to a larger set of initiatives. This helped to achieve a better balance in terms of geographical coverage and social services areas addressed, as well as to identify the evolutionary development of the phenomenon under investigation and its increasing relevance and significance for smart—digital—governance, especially at city level.

Literature Review and Design of the Conceptual and Analytical Framework

The first milestone of the research project was the development of the IESI conceptual and analytical framework, according to which the analysis of the initiatives has been carried out. As showed in Fig. 1, the conceptual and analytical framework is the result of a systematic literature review aimed to provide the state of the art on domains related to the phenomenon of ICT-enabled social innovation. The review was deployed through (1) the definition of a combinations of search keywords and databases engines, (2) the review of over 1000 references of academic literature, grey literature, and policy documents, and (3) the critical appraisal and synthesis of results.

The literature review allowed the development of the IESI conceptual and analytical framework already in the first year of activity. The literature review was further extended in 2015 and 2016, while the IESI conceptual and analytical frameworks were thoroughly reviewed in 2017. Importantly, a community of over 150 experts with different disciplinary and sectoral backgrounds actively contributed to shape and validate the IESI research, by providing theoretical and technical expertise, by helping identify and document initiatives, and by disseminating the project results.

The literature review and the contribution of the experts allowed to develop the following hypotheses addressing key smart governance-related issues that the project has tested:

- Systemic initiatives are mainly happening at the local level and local authorities, especially cities, have a key role acting as catalysers and enablers of social innovation and digital governance.
- The involvement of the beneficiaries of specific services could be a first step to improve the ability of cooperation of the stakeholders and to expand in the future the collaboration with the wider local community too, with particular importance for 'smart city' governance.
- Social (policy) innovation and new public–private collaborative practices emerge to strengthen the modernisation of the European social agenda, with public actors acting as a orchestrators and amplifiers of innovation and resilience into a varied array of welfare policies and governance models. These include integrating preventive measures to fight poverty and social exclusion, active labour market policies, integrated health and social services to improve childcare, and education systems, as well as promoting work–life balance and active aging and long-term care.

The original IESI conceptual framework is summarised in Fig. 2, where ICT-enabled social innovation is at the centre of social services provision. As highlighted by (Misuraca et al., 2015): *'ICTs act as enablers to achieve the interrelated social investment goals. However ICT-enabled social innovation is also shaped by other*

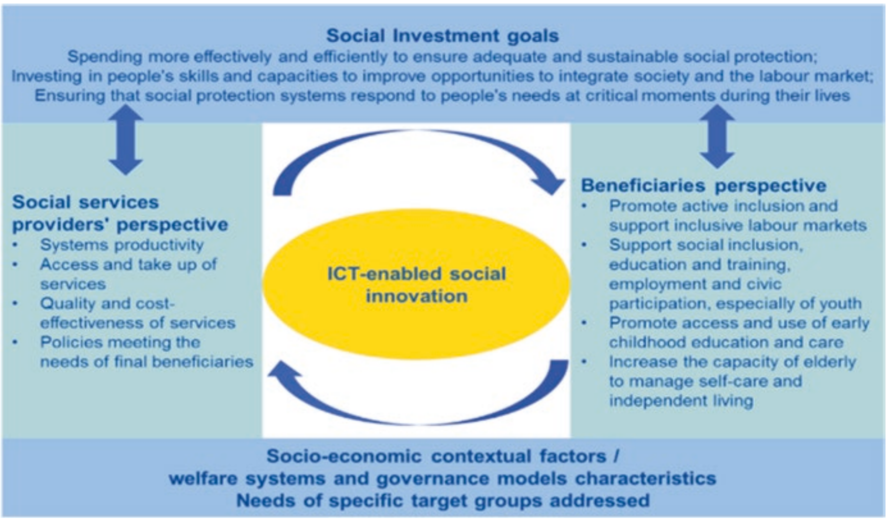

Fig. 2 ESI conceptual framework. (Source: Misuraca et al., 2015)

exogenous factors like the socio-economic context, welfare systems and governance model characteristics, and the needs of specific target groups'.

The conceptual framework is built on the lively debate on the relationship between social innovation and other types of innovation, such as technological or organisational innovation. For instance, Butzin et al. (2014) argue that social innovation should be considered an independent research field with its own rules and eventually its epistemic community whereas Haxeltine et al. (2015) argue for a theory of transformative social innovation, able to explain how social innovation leads to new forms of social interaction that empower people to undertake strategies and actions, eventually leading to systemic change. Hochgerner (2013) argues for a notion of innovation which is paradigmatic since all innovations are socially relevant.

The IESI conceptual framework has in turn been operationalized in an analytical framework summarised by Fig. 3 and briefly described below.

In summary, there are four dimensions to the IESI analytical framework, against which all the initiatives in the IESI knowledge map were analyzed in order to test the research hypotheses:

1. *Typologies of ICT-enabled innovation potential,* on a scale which goes from purely technical innovation—simply facilitating automation of repetitive tasks to radical innovation, where the use of ICT is not only instrumental to service delivery but also leads to paradigm shifts that reframe specific problems, as well as widening the scope for possible solutions.
2. *Levels of governance of service integration,* showcasing the levels of 'coordination of operations across traditional functional units in the public sector, and also across other non-public sector providers, the aim being to put the final users/

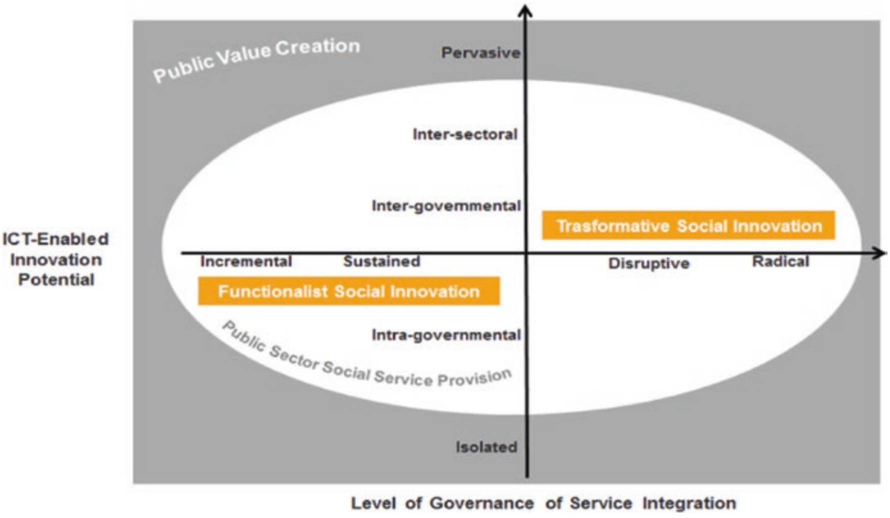

Fig. 3 IESI analytical framework. (Source: Misuraca et al., 2015)

beneficiaries (including intermediaries) in the centre and treat their needs holistically' (Misuraca et al., 2015).

3. *Types of service integration,* detailing the type of service integration, which could occur at the level of funding, administration, organisation, or delivery.
4. *Elements of social innovation,* on a scale which goes from need-driven social innovation to co-creation processes where relationships among stakeholders and with users are radically new, and public value is allocated/reallocated to meet citizens' needs.

Each of the four dimensions will be interpreted through the lens of different conceptions emerged from scientific literature, such as functionalist vs. transformationalist social innovation approach (Bouchard, 2006) or weak vs. strong social innovation (Laville, 2014):

- *Functionalist approach/weak social innovation:* It is an answer to social problems and creates services that meet demands to which neither the State nor the market has responded.
- *Transformationalist approach/strong social innovation:* It is a way of transforming institutions, contributing to institutionalising new solidarity-related practices, standards, and rules founded on values inherent to solidarity. In this perspective, the resolution of social problems brought about by social services is part of a broader perspective of institutional reform.

In 2017, a new set of questions were introduced in the IESI template for data collection, and the frameworks were reviewed to better take into account the changing policy context as well as results of the previous 3 years of mapping, showing that the most innovative initiatives were happening at the crossroads between public and private welfare. In this context, a specific element that was considered was the relationship between social innovation and the resilience of a community, or city authority for instance, to embedding possible disruptive changes that could be enabled by introducing innovative governance models and digital innovations.

The reviewed conceptual and analytical frameworks are summarised in Fig. 4 and Fig. 5 below.

Mapping and Analysis of the Initiatives

In the first year of activities, the JRC IESI team built an inventory of 140 cases of ICT-enabled social innovation in the field of Personal Social Services of General Interest (PSSGI), out of which 70 were selected to be part of the IESI Knowledge Map. The focus of the first round of mapping was on integrated approaches to the provision of social services and active and healthy aging and long-term care. The second 'round' of the IESI mapping (2015) was conceived to better structure the field of analysis integrating the IESI knowledge base with a sample of initiatives

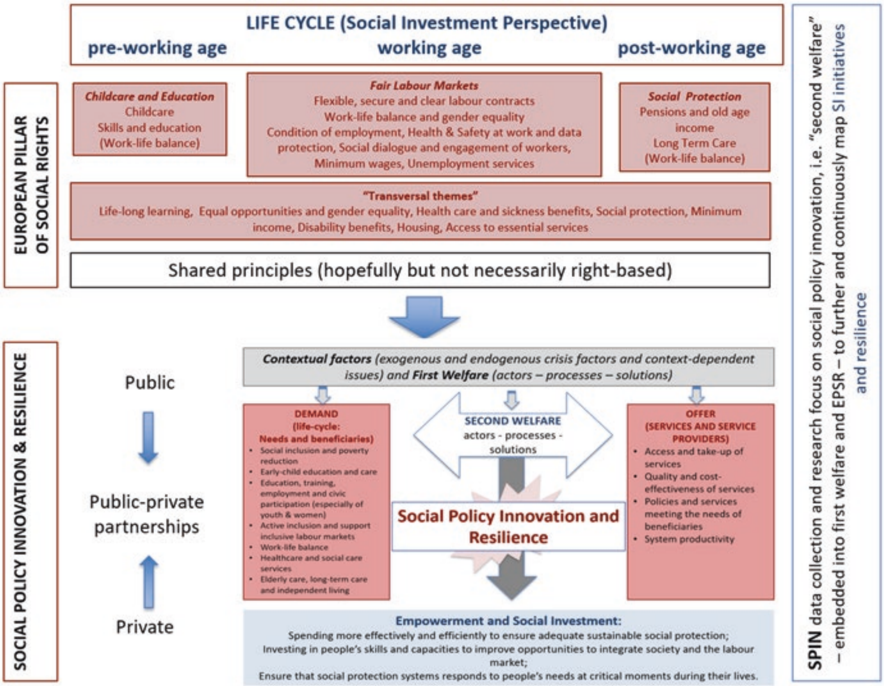

Fig. 4 Reviewed IESI Conceptual Framework integrating a resilience perspective

illustrative of different welfare systems. Two hundred and eighty initiatives were collected as part of the IESI inventory 2015, representing all EU28 Member States and some countries that are considered vanguard in the field under analysis, as well as all the categories of PSSGI. Out of these 280 initiatives, 140 were further documented and analyzed together with the 70 initiatives already mapped in 2014; this formed the IESI knowledge map 2015, composed of a total database of 210 ICT-enabled social innovation initiatives promoting social investment through integrated approaches to social services delivery and presenting evidence of impact achieved. Thematic analyses were also performed in three areas of particular relevance, providing insights into: (1) the role of social enterprises to support social services delivery; (2) the implications of ICT-enabled social innovation to support active inclusion of young people; and (3) active and healthy ageing and long-term care. The third 'round' of the IESI mapping in 2016 brought the total number of initiatives in the inventory to more than 600, 300 of which were mapped for the analysis. Finally in 2017, 191 further initiatives where added to the inventory, out of which 100 were mapped to test the revised framework, with a specific focus on resilience and governance innovation (Misuraca et al. 2017).

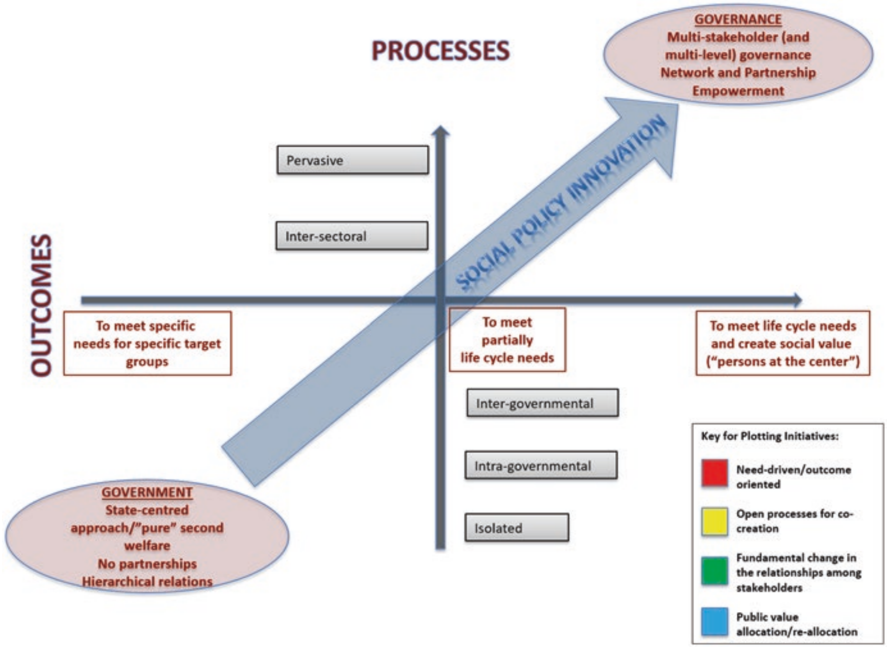

Fig. 5 Revised IESI Analytical Framework for 2017 analysis, integrating a resilience perspective

Results

Comparative and Chronological Analysis of the Typical ICT-Enabled Social Innovation Initiatives

Taken all together the merged database (including all the rounds of inventory and mapping from 2014 to 2017) counts 791 initiatives and 400 mapped cases. While the sample is not statistically relevant, given the fact that initiatives were selected on the basis of the aforementioned rationales, the sheer size of the IESI exercise makes it interesting to note trends—for example the fact that some core characteristics tended to vary from the consolidated database to the latest year (2017), whereas others remained fundamentally unchanged, thus presenting a general trend in the evolution of ICT-enabled initiatives through time.

Variation in Terms of Status of Initiatives

The status of initiatives seemed to remain stable through time: both in 2017 and within the whole consolidated database roughly 90% of initiatives were still operating at the time when the analysis was conducted. Also, the areas of intervention remained particularly static through time, with Social Inclusion being consistently the predominant PSSIG (21–23% of all cases both in 2017 and in the consolidated database), and civic engagement following with roughly 13%.

Variation in Terms of Technologies

In terms of technologies, social networking was consistently the most commonly adopted one among those available on the market, while the promotion of social and active participation decreased significantly its role in 2017 with respect to the other years. The latest analysis showed how such category contributed to 38% of active inclusion technologies, which is still a significant share, but not as much as before (48% across the 4 years).

Variation in Data Use

An important element to consider in terms of governance refers to the use of data. In the sample analysed, data use is strongly oriented towards own data collection, and increasingly so (44% across the 4 years and 57% in 2017), thus showing an even decreasing percentage of initiatives adopting different type of data use through time (see Fig. 6).

Looking at the 2017 database, in particular, we found a clear divide between the United Kingdom (and partially the United States) and the rest of the world. Indeed,

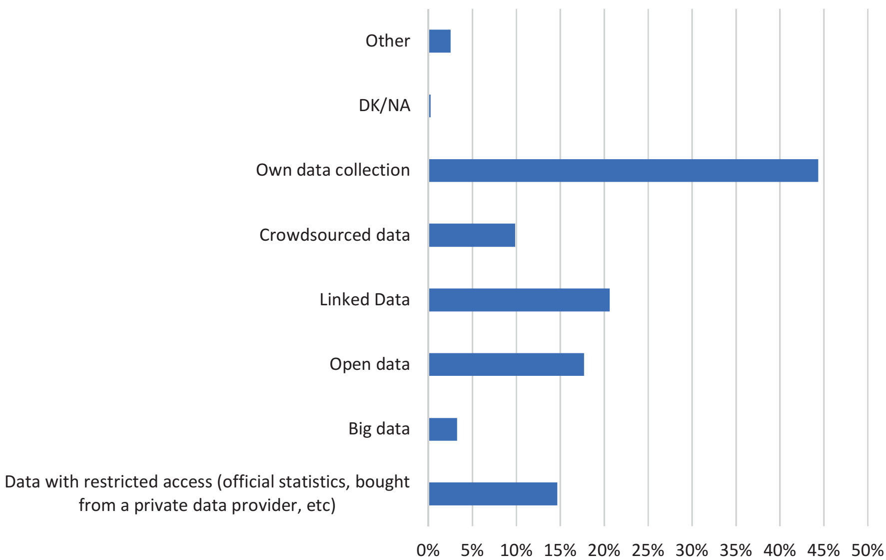

Fig. 6 Use of data

the two countries contribute to 84% of all initiatives that make use of shared data techniques, while in all other countries no more than one to three initiatives employed any of them.

Perhaps related to the somewhat poor level of innovation in the use of data is the decreasing trend concerning the level of ICT innovation potential recorded across different years, with 57% of all cases falling in the top classification (radical and disruptive), and only 34% in 2017.

Variation in Terms of Service Integration

On the other hand, positive signs come from the increasing levels of service integration: while only 29% of all initiatives (across the 4 years) displayed 'pervasive' integration, such category reached 32% in 2017.

Variation in Terms of Partnerships

While formal partnerships continued to dominate ICT-enabled services and the primary stakeholder remained strongly associated to the third sector, in terms of scale of implementation the local dimension grew from 25 to 29% in 2017 (thus totalling an increase of roughly 20%).

Variation in Terms of Strength of ICT-Enabled Social Innovation

At the same time, the strength of the ICT-enabled social innovation flourished in 2017 with respect to previous years (37% compared to 29%).

Variation in Relation to the Evidence of Relevant Policy Outcomes

Similarly, the strength of the evidence on the relevant policy outcomes grew from 26 to 37% ('strong' category), thus signalling a growing interest and need by social services to devote resources to increasingly reliable evaluation systems. The portrait of the typical ICT-enabled social innovation initiative that comes out of this comparative and chronological analysis is that of an increasingly locally oriented and third sector-led initiative, devoted mainly to social inclusion and focussing more on its own integratedness and the quality of its monitoring standards than to the application of radical technologies to the solution of social issues. This means that, on the one hand, some ground still needs to be covered in order to fully exploit the potential of ICT in the welfare domain, and, on the other hand, that as it stands today some of the most promising social services appear to have adapted to an ICT-starved environment by applying other forms of innovation that are more concerned with the way initiatives are run rather than with their contents and the technologies applied by them.

Analysis of the 2017 Mapping

Looking now in more detail at the 2017 mapping, it is worth to report the findings that are key for testing out research hypotheses. The findings are presented below, against the dimensions of the IESI analytical framework.

Typologies of ICT-Enabled Innovation Potential

With the exclusion of international initiatives, two of which have radical innovation potential, local systemic initiatives are the most innovative group with 37% of them presenting technical or sustained potential, and 25% disruptive potential, where only the 7% of national system initiatives present disruptive/radical levels of innovation. The same trend can be spotted for strength of ICT-enabled social innovation potential, where, all together, local and regional initiatives perform better than any other group. This is significant as it shows how smart governance at city level is indeed somehow emerging and innovative models based on social innovation are consolidating at local level.

If we look at initiatives active at the international level, beside the United States and India, the countries whose policy innovation paradigm appears to be more open are, on the one hand, central and eastern European countries (Germany, Estonia, Croatia, Romania), on the other hand, nations with a strong background of social innovation (Finland, United Kingdom, the Netherlands). In fact, initiatives that operate at an international scale are significantly more likely to display a radical or disruptive innovation potential (45% with respect to 34% recorded in the whole inventory), and less likely to display a technical or sustained innovation potential (55% with respect to 66% recorded in the whole inventory).

Concerning the role of the public sector in financing initiatives two main trends could be identified: firstly, it tends to increase as we move from a broader to a narrower scale of implementation (i.e. from the international to the local level); and secondly, it also tends to increase as we move towards less traditional types of financial instruments (e.g. impact investing and public–private partnerships). The countries who fare better in turning local systemic initiatives into high innovation potential are unsurprisingly Italy, the United Kingdom, and the United States, but it is important to note that the significance of this result may be hampered by the relatively small sample size. Nevertheless, the importance of this finding resides in the fact that investments with a social impact mission are better governed at local level and city and regional administrations should play a pivotal role in setting up such instruments and mechanisms able to link financial and digital innovation with social outcomes.

Levels of Governance of Service Integration

If we look at beneficiaries, the aggregate data concerning the target groups (final/main beneficiaries) of the inventory initiatives show a spread-out distribution with a few interesting trends: close to half of the initiatives include the general population as part of their beneficiaries (42%), and another strong emphasis is noticeable on low income people (14%). Among the young generations—another highlight within the 2017 inventory—the most targeted segment is the one from 20 to 24 years of age (14%), followed by teenagers (13%) and the segment 25–29 years of age (9%). These trends capture very well the focus of second welfare initiatives on providing multiple life cycle needs of multiple target groups (with nearly 35% of initiatives in the sample falling in this category), therefore complementing first welfare provisions by taking a social investment approach. Indeed, the majority of the initiatives in the mapped sample (59%) deal with multiple life cycle needs while only a relatively small 16% of initiatives were targeted specifically at one target group. This is of course also in line with the fact that the demand for increasingly personalised and diverse welfare services—which are not or not sufficiently covered by the public sector—is raising steadily all across Europe, including within the wealthier classes. The focus on youth and new poverties moves in the same direction, responding to emerging needs in the aftermath of the financial crisis and in line with the ongoing process of change in family structures and in the labour market that more and more asks for flexible and well-trained labour force. Interestingly, the areas mirror very closely the priorities put forward by the Commission in its MFF proposal, particularly for the next European Social Fund. This alignment is further increased if we look at the areas of service offered, with social inclusion, civic engagement and education/employability being by far the more represented categories, and preventative approaches to welfare services representing another well populated area.

These two elements are cornerstone of both the Social Investment Package and the EU Pillar of Social Rights which deserve to be brought into the future design of EU welfare policy structure. In fact, an analysis carried out on initiatives belonging to these sectors proved they performed significantly better than the average in terms of strength of ICT-enabled innovation potential, with 16% less initiative showing a weak potential, and 5% more initiatives showing strong potential.

Types of Services Integration

If we take a closer look to the roles of stakeholders in the design, funding, organisation/management, delivery and evaluation of initiatives, we will see that in most cases involvement for each stakeholder type is relatively flat across each area, that is to say they participate roughly equally in the design, funding, organisation and evaluation of initiatives. The two most active groups are local/regional authorities and third sector. The most interesting points come from areas where this trend of active stakeholders being active across all areas breaks down. For instance, the EU is involved in the design and funding of a handful of initiatives, but is not involved in any other capacity, even if it is important to remember the capacity of EU funding to activate the leverage and institutionalization processes (see also below in this paragraph). Similarly, the financial sector is very active not only in funding but also in design and delivery, but have little involvement in either evaluation or organisation of these initiatives. This is of course also because, in most impact investing initiatives, impact evaluations must be carried out by independent third parties. Surprisingly, while the role of the financial sector in the so-called 'second welfare' initiatives (Ferrera & Maino, 2019)[3] is clearly important (with financial institutions and insurers playing a role in the 22% of mapped initiatives), only around 10% of the initiatives put financial innovation at the core of their innovation strategies. Community groups are unsurprisingly active across most areas but have limited involvement in funding. It is also clear that there is significantly less activity in the area of evaluation across all groups than other areas of the initiatives. This is an important element, which deserves to be stressed; evaluation of the different characteristics of social innovation initiatives, including their efficiency and the achievement of results, is a fundamental step in the delivery chain, which is often overlooked due to the lack of a 'culture of evaluation'. Indeed, since the objective of social policy innovation is to combine economic and social growth, it is important to establish a systematic and shared approach to evaluation with clear indicators that could help to identify what works and how and what should be improved, changed or abandoned. In this sense, perhaps the sole quantitative evaluation seems insufficient because it is more useful to grasp the economic impact than the social one; therefore, qualitative dimensions and variables should also be included in the evaluation system. EU and national governments are among the entities that are less involved in the evaluation of initiatives, whereas relatively more active in this direction is the third sector, local governments, intermediaries and local communities.

Resilience

Finally, if we look at resilience, an important topic included in the revised analysis, the mapped initiatives display a number of attributes that contribute to their resilience in changing environments. For the majority of initiatives (55%), their resilience can be attributed to their ability to experiment and innovate. Interestingly, relatively few (21%) attribute resilience to an ability to react to changing circumstances, and flat hierarchies (13%). However, looking at the qualitative open questions concerning resilience, it is evident that all the stakeholders of the mapped initiatives are putting in place some strategies to allow the initiative evolving over time to take into account mutating contexts and needs. Therefore, even if their resilience is not rooted in their capacity to respond to fast changing social contexts, they seem well aware that this is the direction to take. Soft factors such as the emphasis

[3] The concept of Second Welfare puts at the core of the analysis social innovative measures and investigate the role of multi-stakeholder systems of governance in order to make the social protection system more efficient, adequate and sustainable (Ferrera & Maino, 2019).

on learning and collaboration over blame and a high social capital, on the other hand, are important resilience elements. Essentially, data on resilience factors seem to confirm that experimentation and technological advancements—both in the area of service provision, and in the area of smart management of service provision—are crucial to the success, efficiency and sustainability of initiatives aimed at contributing to the modernization of welfare systems. This has implications for the debate on 'smart governance', as the elements identified above should be considered central to a policy of social innovation and smart cities development, which are instead often limited to the technological aspects of the innovation and do not look at the ecosystem approach and social impact of initiatives.

Conclusions

Testing Research Hypotheses

This section aims to summarise how the result of the research project support or contradict our original hypotheses.

> *Systemic initiatives are mainly happening at the local level and local authorities have a key role acting as catalysers and enablers of social innovation and digital governance.*

Local systemic initiatives are the most innovative group in our sample and this applies also for strength of ICT-enabled social innovation potential, where, all together, local and regional initiatives perform better than any other group.

International initiatives that operate at an international scale are significantly more likely to display a radical or disruptive innovation potential and less likely to display a technical or sustained innovation potential.

The research showed that the European Union is already exploiting the power of a network approach that goes beyond national service integration, an element which shall be further encouraged in order to develop a stronger and more resilient pattern of social innovation. Supporting a similar approach to bridging the gap within the initiatives operating in different European countries also favours a more efficient social spending, allowing to stimulate effective results by supporting a systemic approach rather than allocating a greater budget.

> *The involvement of the beneficiaries of specific services could be a first step to improve the ability of cooperation of the stakeholders and to expand in the future the collaboration with the wider local community too with particular importance for 'smart city' governance.*

The fact that several of the mapped initiatives are recent or at the early stages of implementation indicates that the hypothesis can be confirmed. The research also shows that the participation from beneficiaries occurs with some sense of empowerment to act that may be key to channel private resources towards bottom-up social finance initiatives which can complement 'top-down' initiatives driven by larger organisations and the public sector.

Social (policy) innovation and new public–private collaborative practices emerge to strengthen the modernisation of the European social agenda, with public actors acting as a orchestrators and amplifiers of innovation and resilience into a varied array of welfare policies and governance models. These include integrating preventive measures to fight poverty and social exclusion, active labour market policies, integrated health and social services to improve childcare and education systems, as well as promoting work–life balance and active aging and long-term care.

Raising budget constraints and austerity-based structural reforms weakened those processes of recalibration that before the crisis had sustained the European social agenda, with the main consequence of growing asymmetries inside the European area between countries that retain room for investment in welfare services designed to address new social risks and pursue a social investment-based agenda and countries, burdened by high public debt, de facto unable to promote any kind of reform beyond the progressive reduction of social benefits.

This has resulted in a huge disparity between the goals set by the European Union's social agenda and the budgetary constraints especially in countries burdened by high public debt. Fiscal consolidation cannot be Europe's main way out of the crisis and increased social investment is needed. But how can one achieve the objectives of the European Social Agenda, especially after the launch of the European Pillar of Social Right in times of declining public resources? In response to a demand for a more 'efficient' use of the scarce public resources available and for further public and private resources to be allocated towards welfare services, social policy innovation can contribute—and is indeed contributing—to strengthen new collaborative solutions aimed at renovating social policy design and welfare funding.

Investment in social infrastructures, social innovation initiatives and digital transformation require new combined public–private resources able to provide economic and long-term social outcomes. SIBs and impact finance are a part of a wider financial ecosystem that is emerging to channel further resources towards social economy organisations, social infrastructures, and social innovation initiatives. According to the OECD (2016a, 2016b), the emergence of these financial tools can contribute to strengthening welfare provision in times of scarce public resources and improving the performance of non-statutory services. Other authors expressed several concerns regarding the development of Social Impact Bonds (SIBs) as they encourage equity products in the field of social services and a substantial re-commodification of the welfare supply. Other concerns regard the risk of creaming-effects. In fact, SIBs (as well as 'payment by result' schemes in general) can create incentives for providers, in order to avoid more risky projects. As pointed out by Azemati et al. (2013) and Hazenberg and Hall (2016) another risk comes from the increasing focus on just a few large not-for-profit organisations and bigger financial investors, able to broker the majority of the mobilized resources. Despite common pressures to move towards impact finance tools, very little evidence is available on the role played by the various public and private actors involved in these processes: the state, as direct investor and/or collector of private resources towards welfare services and social innovation, the local authorities, the private investors (banks, investment funds, venture capital, philanthropic foundations), the national promotional banks, and the institutional investors (pension funds, insurance companies). Against this background, a comparative framework is needed to deepen the knowledge of the various national models, so as to provide insights able to enhance the room for public and private long-term investment towards social innovation at local level. In this regard, comparative research on the relationships between social provision and financial markets deserve a greater attention, especially with regard to impact assessments for social policies or social infrastructure projects.

Moving to the so-called ‘second welfare’ domain, recognising the crucial role played by public welfare, the 2017 IESI mapping shows also that first and second welfare are not two separate entities, but two intertwined spheres capable of fading into one another according to different policies, contexts, and areas of need. For this reason, the role of public institutions at different levels of government remains of great importance in connection and partnership with non-public actors. When first and second welfare provisions are aligned and synergic, there we have higher levels of social policy innovation. In fact, in contrast to what is claimed by some literature on social entrepreneurship, the important role of private/non-for-profit actors within social innovation does not necessarily entail a minor role for public institutions. Most of the initiatives considered in the 2017 IESI mapping were promoted by partnerships involving public authorities, private, and/or non-for-profit actors, and, in most cases, this was an element of innovativeness of the initiative in itself. In this renewed context, especially the role of municipalities seems to shift from providing services to promoting networks. Public actors (especially at the local level) usually act as ‘policy entrepreneurs’, coordinating multi-stakeholder networks and pushing for the introduction and implementation of social innovation programmes and initiatives—using, when available, also ‘external’ resources (such as EU, national, and regional funds) as a ‘financial leverage’. Moreover, public actors will continue to act as guarantor of the common good, of the fact that social policy innovation initiatives are directed to grant the rights of the many and not the few and that inequalities are reduced. This would mean that it will be necessary to redesign the policy-making process, opening it to all social stakeholders; overcome the centralization of Central Government power, devolving part of its authority among other institutional levels; support networks and partnerships instead of hierarchy and bureaucracy and include civil society in the decisional process and in the implementation of policy, according to the welfare mix approach.

Moreover, in a context of permanent austerity and of welfare state crisis, States need innovative ideas that take into account the complexity of the problems and then foster solutions that permit welfare systems to learn, adapt, and occasionally transform without collapsing. More importantly, States need to build the capacity to find such solutions over and over again. Resilience theory focuses on the balance between continuity and change, a continuous cycle of release, reorganisation, growth, and consolidation that characterises all resilient living systems. Some ideas fail, but others become new products, programmes, processes, or designs that attract resources and become part of the established system. Here we can see a potential pattern: the association of old and new ideas in the idea-generation stage; a shakeout of competing ideas and organisations in favour of those able to attract the most resources; a consolidation phase of successful ideas and organisations and the institutionalisation of social innovations so that they become the solution to be implemented at a larger scale.

One of the most important attributes that a social policy innovation approach can offer is that it helps to understand the process by which social and welfare systems adapt or are transformed. In particular, this approach sheds light on the various actors (both public and private), their interests, and their role. The 2017 IESI mapping went deeper into the analysis to explain the role played by stakeholders and social entrepreneurs at different points in the innovation cycle and how these roles are devoted towards finding opportunities to connect an alternative solution to the resources of the dominant system. The analysis pointed out that in many cases this kind of transformation takes many years to occur. It requires a long period of preparation in which an innovative alternative is developed and then scaled up when a window of opportunity opens. Studies of resilience at the community, organisational, and individual levels suggest that the characteristics that these organisations and communities share are low hierarchy, a strong ability to quickly respond to changes, a high degree of flexibility in respect to the social risks and needs, an emphasis on learning and collaboration over blame, room for experimentation and innovation, high social capital, in particular reliability, leadership, social networks, and mutual respect (Maino & Ferrera, 2015; Westley, 2013), creating a virtuous cycle that in turn builds the resilience of the entire welfare state and of the whole society.

To conclude, we need to be aware that the capacity of social policy innovation to affect and to renew welfare systems differs according to the territorial level one takes into account. Many socially innovative initiatives seem indeed having affected local social policies. However, the degree and capacity of 'up-scaling' is limited so far; most of the measures implemented remain local initiatives and are not mainstreamed into national welfare systems. This finding strongly contrasts with the objectives of the European Pillar of Social Rights which conceives social policy innovation as a way to test the effectiveness of social policy reforms on a small scale, that is, before up-scaling them in national welfare systems, which has to remain the ultimate and strategic goal.

Therefore, the responsibility of leadership to protect the collective interests is and will be crucial, and it has to be accompanied by a selective and focused management of resources, within a development strategy that promotes cooperation between the various local, national, and EU actors and transforms the territory from an 'arena' in which various actors interact into a real 'collective subject'. Establishing a 'Social Policy Innovation Expert Forum' charged with the development of such a strategy and the evidence base to support its implementation would be a step in the right direction.

Contribution to the Debate

From a research perspective, based on IESI findings, two areas in particular would deserve broader investigation: impact investing and multi-stakeholder governance.

Concerning impact investing, the preliminary findings—particularly in the 2017 mapping—provided insight about the nature and the extent of private resources mobilised towards welfare services and social innovation initiatives. A growing body of analysis, including the recent report of the High-Level Task Force on Social Infrastructure[4] in Europe, has begun to investigate the rise of alternative sources of funding for welfare provision, including 'impact finance' tools aimed at involving private investors, banks, private foundations, and venture capital funds in new financial investments funding social enterprises, private providers, and local authorities. Increasingly, private investors, social enterprises, and public authorities are planning to develop this kind of varied financial tools for welfare provision, especially in Anglo-Saxon countries.

The IESI knowledge base and related knowledge community can provide a helpful tool for policy-makers and practitioners across Europe, and particularly if connected with the creation of a Forum of experts which could not only expand and further analyse the dataset but facilitate experimentation, replication, and scaling-up of successful initiatives, while also contribute to modernise relevant EU and national policies. Indeed, if today Social Policy Innovation—similarly to social innovation—has mainly been intended as a quasi-concept, without turning into a proper knowledge paradigm, it is precisely because of the lack of a critical mass of researchers, policy-makers, and practitioners committed to systematise this concept building on academic research and on the more policy-oriented existing evidence base, as well as to raise citizens' awareness about the importance of the subject.

Moreover, as a consequence of blurring boundaries between the public and private sphere and between private for-profit and not-for-profit organisations, new modes of governance, and public–private partnerships are emerging. The governance of this emerging 'second welfare' paradigm requires further research, with a focus on measurable social outcomes and methodologies aimed at avoiding negative externalities on users and, no less importantly, on social workers involved in these processes. Further research is also needed to provide comparative analysis aimed at mapping-out the variety of financial ecosystems in the different European countries, including at the regional and local level, allowing to focus on which institutional and social factors enable participatory approaches to social finance and social change. In addition, the rise of new public–private financial partnerships highlights the need to better understand how the various European funds could be

[4] The High-Level Taskforce on Social Infrastructure in Europe was promoted by the European Long-Term Investors Association (ELTI) and established in February 2017, in close consultation with the European Commission: cf. Fransen L., del Bufalo G., Reviglio E. (2018), *Boosting Investment in Social Infrastructure in Europe,* EUROPEAN ECONOMY Report of the High-Level Task Force on Investing in Social Infrastructure in Europe.

matched with national and local initiatives. In this vein, country-by-country analysis need to be combined with cross-country analyses, so as to share common impact investing methodologies.

The results of the analysis have also clear implications on the smart governance and smart cities debate at both academic and policy level. First of all, it is clear that ICT-enabled social innovation has a strong potential to empower citizens participation in the life of a community, and thus enhance civic engagement which can result into innovative collaborative governance. At the same time, leveraging on the capacities of digital technologies, new services can be designed and delivered providing personalised solutions to improve conditions of disadvantaged groups and help shape a better community's life. This of course requires the consideration of all elements that are essential for a smart management of service provision and policy innovation, not only addressing the technological dimension of governance rather stimulating an effective ecosystem approach which is crucial to the sustainability of initiatives aimed at contributing to the modernization of welfare systems and building resilience of smart governance models, especially at local and city level.

Acknowledgements This chapter builds on results from the research project on 'ICT-enabled Social Innovation to support the Implementation of the Social Investment Package' (IESI) carried on by the European Commission's Joint Research Centre, in partnership with the Directorate General for Employment, Social Affairs and Inclusion, under the leadership of Gianluca Misuraca, Senior Scientist at JRC Seville. See https://ec.europa.eu/jrc/en/iesi The research has benefited of many contributions from external researchers and experts, and for the analysis contained in this chapter a special thanks goes to Amerigo Lombardi of Plus Value.

DisclaimerThe views expressed are those of the authors and may not be regarded as stating an official position of the European Commission.

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Analyzing the Influence of the Smart Dimensions on the Citizens' Quality of Life in the European Smart Cities' Context

Manuel Pedro Rodríguez Bolívar

Abstract In the last years, the creation of public value in the smart cities (SC) is conceived as a strategic approach to public management based on the promotion of networked governance with the aim at improving the quality of life (QoL) of the cities' residents (Rodríguez Bolívar, Proceedings of the 52nd Hawaii International Conference on System Sciences, 3325–3334, 2019). This chapter seeks to analyze whether SC are those with a higher QoL in the urban environment as well as to investigate the smart dimensions that could have an influence on the QoL of the cities' residents. Findings based on a sample of European smart cities indicate that the smart city's promise of increasing the citizen's QoL is true, but it seems to be mainly focused on the outcomes (smart living dimension) and not on other smart dimensions that focus on the process to obtain the outcomes (smart governance, smart economy, or smart environment, for example).

Introduction

In the age of new technologies (ICTs), one of the main challenges and urban dimensions of the new wave of cities is the pursuit of increasing the quality of life (QoL) of the cities' residents (Makkaoui, Lachhab, & Bakhouya, 2017). Indeed, citizens are exerting pressure on the public administrations not only for implementing ICTs but also for them to have an impact on their QoL through the generation of public value.

The smart city (SC) concept arises in this context as a first attempt to use the great potential that ICTs offer to support the creation of public values through democratic governance (Moore, 2013), improving local democracy and making public administrations efficient (Allwinkle & Cruickshank, 2011). Therefore, although there remains some lack of clarity over what public value is (Williams & Shearer, 2011), in this chapter public value creation must be understood as a strategic

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_11

approach to public management based on the promotion of networked governance (Moore, 2013) with the aim at improving the citizen's QoL (Rodríguez Bolívar, 2019).

This issue makes public administrations to go beyond the pursuit of efficiency towards the generation of common values that citizens and other stakeholders desire (Williams & Shearer, 2011) with the active help of co-producers and partner organizations (Benington, 2011).

Thus, based on the post-material position combined with a technocratic perspective on good governance, the concept of public value is built on the use of public assets to improve the QoL at individual and collective levels (Moore, 2017) through citizen satisfaction with the achievement of social outcomes (Boivard & Loeffler, 2012; Moore, 2013) and instituting both innovative collaboration (Meijer & Rodríguez Bolívar, 2016) and democratic governance in municipalities (Moore, 2013), mainly with the use of new technologies into the SC's framework (Thorne & Griffiths, 2014). Therefore, public value management situates public organizations in a wider network of stakeholders who have to be involved in the public value creation (Moore, 2013; Williams & Shearer, 2011), in which the use of smart solutions becomes the main goal for improving the QoL (Bătăgan, 2011; BSI, 2014; Stockholm, 2006).

Consequently, public managers must focus on the identification and measurement of the elements necessary to create public value (Sherman, Weinberg, & Lewis, 2002), which is the result of aligning three interrelated processes in a strategic triangle (Moore, 1995): (1) defining public value, (Allwinkle & Cruickshank, 2011) building and sustaining a group of diverse stakeholders to create an authorizing environment, and (Barsi, 2018) mobilizing the resources from inside and outside the organization to achieve the desired outcomes.

Nonetheless, despite the relevance of public value creation, the most striking feature in the public value literature is the relative absence of empirical investigation of either the normative propositions of public value or its efficacy as a framework for understanding public management (Williams & Shearer, 2011). As noted previously, the public value approach is understood as the framework for increasing the QoL in the urban environment and, by this way, this chapter tries to fill the gap in understanding whether the SC framework allows a higher QoL. The first question here is:

RQ1. How is the transition possible from the objective measures of city smartness to an intangible entity of QoL?

On the other hand, smart cities involve the extensive and intensive application of ICT to several spheres of functioning in a city which makes necessary to identify certain characteristics of the cities for their evaluation with a ranking methodology (Giffinger et al., 2007). Although different rankings of SCs have been proposed (Cohen, 2011; Giffinger & Gudrun, 2010; IESE, 2019), a generally accepted methodology is that based on the six main characteristics or smart dimensions identified by Giffinger et al. (2007) (smart economy, smart people, smart governance, smart mobility, smart environment, and smart living). These dimensions are also valid for analyzing the QoL.

In fact, although Eurostat and representatives of the EU Member States have designed an overarching framework for analyzing the QoL through eight dimensions, which feed into the measurement of the overall experience of life (EU, 2016), these dimensions can be identified with, at least, five of the smart dimensions of SCs (all of them except for smart mobility). In particular, these dimensions of QoL seek to capture and balance objective measures of income, living conditions, education or health, with subjective measures such as an individual's appreciation of their living environment, how safe they feel, or whether they can rely on friends/family (EU, 2016).

Despite previous comments, there has been surprisingly little research on the evaluation of the influence of smart dimensions on the QoL, as it is the main expected outcome of embedded smart technologies for cities and citizens into the urban space. Therefore, the second research question of this research is:

RQ2. How can the different smart dimensions influence the citizen's QoL in SCs?

In brief, this chapter seeks to analyze whether the new wave of SCs impacts on a higher QoL in the urban environment and how this impact is produced, analyzing how the smart dimensions could have an influence on the higher level of the QoL in SCs. To achieve this aim, this chapter collects information about the "smartness" of European cities and the widely used QoL rankings in order to test whether the label of SC, as well as the type of smartness of the SC, could be associated with a higher degree of citizen's QoL.

The remainder of this chapter is as follows. The next section makes some comments regarding the link between SCs and the increase of the citizen's QoL in the urban environment. In the third section of the chapter, the empirical research performed is presented, describing the sample selection and the methodology of research. Then, the main results of our study are shown and, finally, the discussions and conclusion section brings the chapter to an end.

The Quality of Life in Smart Cities

The rapid transition to a highly urbanized population has led cities and urban areas to rely on an intensive use of information and communication technologies (usually ICTs), as a way of solving economic, social, and environmental challenges. This intensive use of ICTs has given place to the so-called smart cities (SCs) and has become the best way for improving the QoL in the urban environment as enjoyed by the city's residents (Cunha Rodrigues, 2018). The QoL is, therefore, the broader goal in SC, but it is often linked to all the policies of the local government (Dameri, 2013), which demands the implementation of new governance models (Rodríguez Bolívar, 2018a) where the citizen participation plays a key role for urban planning's commitment to QoL (Cárcaba, González, Ventura, & Arrondo, 2017).

From this perspective, SCs can be considered as an urban strategy aiming at improving the QoL of those in the city, safeguarding the environment and reaching economic development at the same time (Barsi, 2018). In this regard, a study carried out in Spain found that citizens consider QoL improvement and public services quality as the main utilities of smart cities (Centre of Innovation of the Public Service & IE Business School, 2015). Thus, the city governance should be addressed to increase the QoL of the citizens, which makes the evaluation of the smart governance to be linked to the measure of individual well-being and satisfaction in the city in a comparable and dynamic way through the impacts of public policies on the QoL of the citizens (something that goes beyond the mere outputs or services provided) (Cárcaba et al., 2017) since the QoL indexes are considered as tools for measuring long-term public value creation (Benington, 2011), which is a very complex goal (Barsi, 2018).

City rankings have been used as tools for generating discussions and debates on smartness, competitiveness, and QoL, helping to rethink formerly elaborated strategies and development priorities. Indeed, rankings provide an empirical base for assessing specific strengths and weaknesses in a benchmarking process and they can be applied as guiding instruments for future city development, in particular in a functional way (Giffinger, Haindlmaier, & Kramar, 2010). Therefore, the link between SC rankings and QoL rankings seems to be strong that should be analyzed.

In addition, the QoL has been viewed as part of the profile of a “competitive city” too and has been employed by city agencies to make their location attractive to different global capitals, which has emphasized place characteristics instead of adopting other groups’ views of QoL (Rogerson, 1999). The QoL research should then be at the front and center in this process of evaluating people’s relationship to their environment within the city (Jeffres, Bracken, Jian, & Casey, 2009), and QoL metrics should be seriously factored into any smarter strategy (Thorne & Griffiths, 2014).

Nonetheless, aggregated macroeconomic figures have been used in order to track the progress of societies, but it oversimplifies the problem (Cárcaba et al., 2017). So, it is unsurprising that the QoL indexes be relevant to complement macroeconomic figures with socio-economic figures summarizing welfare in society, although measuring the QoL of the citizens is far from being an easy task, being especially at the city level where the information of QoL is still not very well developed (Cárcaba et al., 2017).

In brief, SCs are aimed at creating more participative governments (Rodríguez Bolívar, 2018a) with the aim of taking citizen-centric decisions and improving their QoL through the intensive use of ICTs (Yeh, 2017). This new scenario improves the conditions to achieve a more livable environment and stronger economic prospects to improve citizens’ QoL (Lee, Hancock, & Hu, 2014). Thus, this chapter analyzes whether SCs have achieved their main outcome of getting a higher QoL in the urban environment. Also, this chapter analyzes the “smart” source of the QoL and the influence that the different aspects of smart governance could have on greater levels of QoL. To achieve this aim, the next section of this chapter discusses an empirical research we performed in the European SCs looking for their position in relevant

QoL rankings and investigating the influence of the different smart dimensions on the citizen's perceptions of QoL.

Empirical Research

Sample Selection

This chapter is based on the European setting because the European integration process has reduced differences in economic, social, and environmental standards and norms providing a common market, which makes cities more similar in their preconditions (Giffinger et al., 2007). The data collection method of this chapter is based on two different sample groups of cities. The first one is composed of the largest-size European cities labeled "smart" by a European project sponsored by Asset One Immobilienentwicklungs AG (from 300,000 to one million inhabitants) because large and dense cities are highly productive and innovative (Harrison & Donnelly, 2011) which impacts on a higher QoL for their inhabitants (Glaeser, 2012; Jacobs, 2016).

This selection method (http://www.smart-cities.eu) ranks SCs based on more than 30 factors, grouped into six dimensions (Giffinger & Gudrun, 2010): smart economy, smart people, smart governance, smart mobility, smart environment, and smart living. This phase of our sample selection process collects 88 SCs to the sample selection.

The second group of sample cities is composed of those European cities considered as "Non-smart cities" (NSCs). This second group is difficult to be selected because every city could attain a different level of smartness within a range, rather than falling in "black and white" categories of smartness or not. Nonetheless, while the adoption of up-to-date technologies does not guarantee the success of smart city initiatives, Nam and Pardo (2011) and EU (2016) argue that technology is obviously a necessary condition for a smart city.

Therefore, in this chapter, other 88 European cities have been selected which, according to the criteria indicated above, are not labeled "SCs." To achieve this aim, we have avoided both those cities listed in the European project mentioned before and those that are members of the EUROCITIES network (see http://www.eurocities.eu/), which is composed of the local governments of the main European cities that are working actively to become smart to increase their QoL using ICTs in the city.

To obtain a homogenous sample, the sample cities labeled "SCs" have been sorted by country, and then the same number of NSCs has been selected from each one of these European countries (88 NSCs in total). These selected NSCs have the highest population (once removing those labeled as "smart") since dense cities tend to become smart. In a second stage, this selection process removes the NSCs with a population under 300,000 inhabitants with the aim of using the same criteria as that used for cities classified as SCs. Therefore, the total number of NSCs in this chapter reduces to 12. This way, our final sample selection, following the previously mentioned selection process, consists of a total of 100 European cities (88 SCs and 12 NSCs).

Data and Method

The measurement of QoL is a complex task based on objective data and/or on subjective citizen's perception (Cunha Rodrigues, 2018; EUROSTAT, 2018). Although there are differences between the two methods of measuring the QoL, Kaklauskas et al. (2018) have recently demonstrated that the scores and rankings used have revealed a good level of congruity between the ranks obtained by employing the different methods and data have been proved to be similar.

So, this research collects data from four different relevant QoL rankings, two of them—EUROSTAT and NUMBEO[1]—based on the citizen's feelings or perceptions (participative rankings), and two others—MERCER and EIU[2]—based on the measurement of different quantitative dimensions that encompass the QoL ranking (non-participative rankings).

All QoL rankings used in our research are referenced to 2015 since it is the last year in which all of them have been published simultaneously, although some of them are already updated. Descriptive statistics and graphical methods are used to show the position of the different sample cities in the QoL rankings with the aim at answering RQ1.

Regarding RQ2, this research has been based on the position ranked for each city on each of the QoL ranking and, for the special case of EUROSTAT, it has been based on the responses to a question included in this ranking regarding the satisfaction of citizens with their life into their city and its link with the score that this city has obtained in the European project sponsored by Asset One Immobilienentwicklungs AG (mentioned previously) on each one of the six smart dimensions or characteristics that an SC could have. The hypothesis testing was performed using multiple linear regression models (MLR). The initial proposed MRL model for RQ2 is, the following:

$$\begin{aligned} \mathrm{SL_i} = \beta 0 + \beta 1 * \mathrm{S} - \mathrm{Economy_i} + \beta 2 * \mathrm{S} - \mathrm{People_i} + \beta 3 * \mathrm{S} - \mathrm{Governance_i} \\ + \beta 4 * \mathrm{S} - \mathrm{Mobility_i} + \beta 5 * \mathrm{S} - \mathrm{Environment_i} + \beta 6 * \mathrm{S} - \mathrm{Living_i} \end{aligned}$$

where SL is the position (NUMBEO, MERCER, and EIU) or the proportion of persons who are satisfied living in their city (EUROSTAT), and S-Economy, S-People, S-Governance, S-Mobility, S-Environment, and S-Living are the scores obtained for each one of the sample SCs in each one of these smart dimensions in the European project mentioned before.

Although the total number of sample cities in our research is 100, not all of them appear in all the selected QoL rankings. Nonetheless, the use of all these QoL

[1] See http://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/urban/survey 2015_en.pdf and https://www.numbeo.com/quality-of-life/region_rankings.jsp?title= 2015&region=150, respectively.

[2] See https://www.imercer.com/uploads/GM/qol2015/h5478qol2015/index.html and http://media.heraldsun.com.au/files/liveability.pdf, respectively.

rankings could provide great objectivity to the data collected in our study limiting the influence that particular criteria used could have on these QoL rankings. Thus, the 30.49% of the total European cities included in the EUROSTAT ranking (25 cities out of 82 indexed European cities), the 29.82% of the total European cities included in the MERCER ranking (17 cities out of 56 indexed European cities), the 30.56% of the total European cities included in the EIU ranking (11 cities out of 36 indexed European cities), and the 41.38% of the total European cities included in the NUMBEO ranking (24 cities out of 58 indexed European cities) are included in the sample selection.

Analysis of Results

RQ1. How Is the Transition Possible from the Objective Measures of City Smartness to an Intangible Entity of QoL?

Table 1 in Annex shows the QoL ranking characteristics regarding the range of cities in each one of the quartiles of the rankings as well as the number of European cities included into each one of the rankings. In this regard, while European cities are mainly concentrated on the Q1 and Q2 of the non-participative rankings (MERCER and EIU), they are equally distributed into the different quartiles in the participative QoL rankings (EUROSTAT and NUMBEO). Therefore, results indicate differences between objective measures and citizen's perceptions of QoL, which could mean the existence of a gap between outcomes and the impact that these outcomes could have on the citizen's perceptions of the QoL.

On the other hand, Table 2 in Annex shows the descriptive statistics of the data and collects the position that sample SCs and NSCs get on each one of the QoL rankings. To begin with, sample selection of our study represents, at least, the 30% of the European cities indexed in the QoL rankings, which means that the sample selection of this research allows us to obtain significant findings for future research.

Table 1 Characteristics of QoL rankings

		The range of cities in each quartile					Number of European cities in the selected QoL rankings				
		Total	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Total
Objective rankings	MERCER	230	1–57	58–114	115–172	173–230	31	18	4	4	57
	EIU	140	1–35	36–70	71–105	106–140	18	12	4	2	36
Subjective rankings	EUROSTAT	82	1–20	21–41	42–62	63–82	20	21	21	20	82
	NUMBEO	58	1–14	15–28	29–42	43–58	14	14	14	16	58

Source: Own elaboration

Table 2 Descriptive statistics

		Smart cities														
			Relative frequency over sample	Frequency in Qi position in the QoL ranking				Relative frequency over Qi position of total European cities in the QoL ranking (%)					Standard			
		Frequency	SCs (%)	Q_1	Q_2	Q_3	Q_4	Q_1	Q_2	Q_3	Q_4	Median	deviation	Min	Max	Range
Objective rankings	MERCER	17	19.32	11	6	0	0	35.48	33.33	–	–	40	33.72	6	99	93
	EIU	11	12.50	6	4	1	0	33.33	33.33	25.00	–	33	20.37	10	72	62
Subjective rankings	EUROSTAT	25	28.41	8	5	8	4	40.00	23.81	38.10	20.00	41	24.11	4	81	77
	NUMBEO	24	27.27	7	8	7	2	50.00	57.14	50.00	12.50	23	13.77	2	52	50

Source: Own elaboration

In addition, all sample cities included in the QoL rankings are labeled "SCs." Indeed, NSCs are not present in any of the selected QoL rankings. This result could indicate that the smartness of a city can produce higher QoL.

On the other hand, results in Table 2 in Annex indicate that sample SCs are mainly present in the subjective QoL rankings in which they represent more than the 25% of all sample SCs. Indeed, whereas 25 and 24 SCs are present in the QoL rankings of EUROSTAT and NUMBEO, only 17 or 11 SCs are ranked in the best positions in the QoL rankings of MERCER and EIU.

Nonetheless, although the highest number of sample SCs is concentrated on the best quartiles of all the QoL rankings, it is especially true in QoL rankings based on objectives indicators. In fact, almost all sample SCs are concentrated in the Q1 and Q2 in the QoL rankings of MERCER and EIU. By contrast, these sample SCs are dispersed into the different quartiles in the QoL rankings of EUROSTAT and NUMBEO—see Table 2 in Annex. This result seems to confirm the existence of a gap between objective measures of the citizen's QoL and their perceptions regarding this matter.

Finally, results obtained in the median scores of the sample SCs in Table 2 in Annex confirm that median scores of the sample SCs are below the limit of the Q1 values in the MERCER and EIU rankings, whereas median scores of sample SCs fit within the range of values of the second quartile or in the third quartile of the EUROSTAT and NUMBEO rankings.

In a more detailed analysis of the cities, we can also appreciate graphically the findings in Fig. 1 in Annex. In this figure, we can observe the position of each one of the sample SCs and NSCs in the selected QoL rankings as well as the quartiles in each of the rankings.

RQ2. How Can the Different Smart Dimensions Influence the Citizen's QoL in SCs?

The MLR model is applied to find the statistically significant independent variables to predict citizen's QoL on each one of the analyzed QoL rankings. The summary of MLR results is displayed in Table 3 in Annex.

As it can be seen in Table 3, in all models proposed using each one of the QoL rankings, the value of R^2 ranges from 0.683 to 0.94, which is very high. Also, the independence analyses indicate that the Durbin-Watson test is over 1.5—see Table 3. Therefore, the constructs used are independent.

Also, collinearity analysis is performed using SPSS software. According to our results, tolerance analysis shows that all values obtained for the constructs are under 0.5—see Table 3 in Annex—except for the particular case of the EUROSTAT QoL ranking. These results obtained under 0.5 in the tolerance analyses mean that the probability of multicollinearity is high; only in the case of EUROSTAT QoL ranking there is no multicollinearity. In fact, the lower tolerance scores, the higher

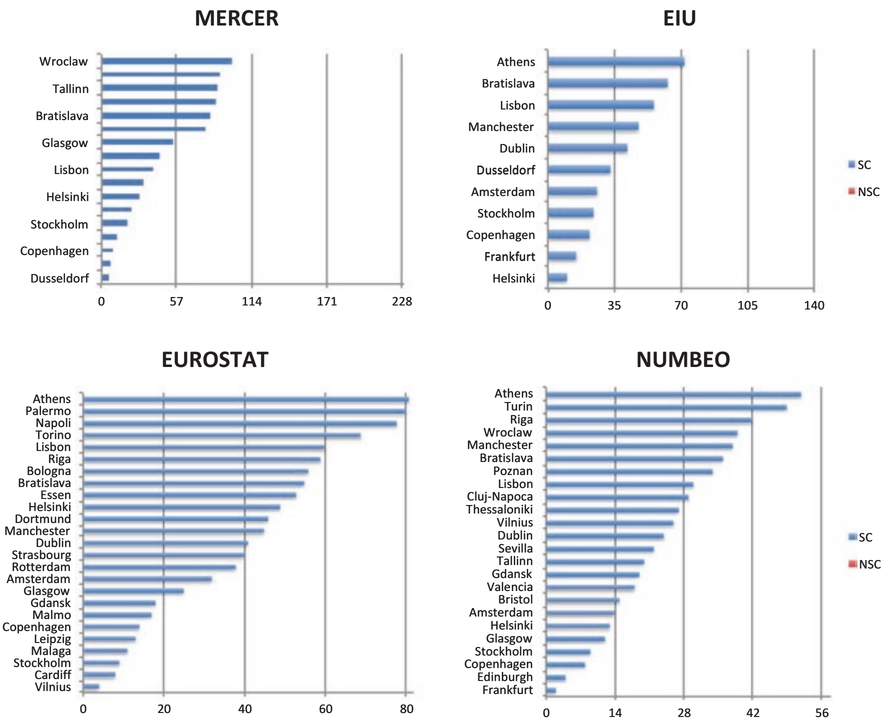

Fig. 1 Objective and subjective QoL rankings—How is the transition possible from the objective measures of city smartness to an intangible entity of quality of life?

multiple correlations, and inversely (Field, 2013). Furthermore, variance inflation factors (VIF) for all independent variables are high and over 2 (except for the case of EUROSTAT QoL ranking), which again implies that the multicollinearity is high.

Therefore, the model that can explain the link between the ranking of SCs and the QoL ranking is that designed for the EUROSTAT QoL ranking. The rest of models have been modified using the stepwise MLR method (backward method). Using this method some attributes are removed until the VIF and tolerance analyses indicate that no multicollinearity problems exist. This way, the final models of our tests are presented in Table 3, in which NUMBEO QoL ranking is linked to smart economy, smart people, and smart environment, MERCER QoL ranking is linked to smart economy and s-governance, and EIU QoL ranking is linked to smart economy and smart environment.

Results of the EUROSTAT QoL model show that smart economy, smart mobility, and smart living are the most important constructs in the citizen's perceptions about their satisfaction of living in their city (p-value under 0.05). Nonetheless, the smart economy seems to show a negative influence on the citizen's perception of QoL.

Table 3 MLR: coefficients and independence and collinearity analysis

Initial models							
Participative QoL rankings							
	EUROSTAT						
	R	R^2	Adjusted R^2	Standard error of estimation		Durbin-Watson	
	0.867	0.751	0.691	4.14986		1.519	
Constructs	Unstandardized coefficients		Standardized coefficients	*t*	Sig.	Collinearity statistics	
	B	Standard error	Beta			Tolerance	VIF
(constant)	90.494	1.111		81.432	0.000		
TOTAL S-ECONOMY	−7.039	2.025	−0.567	−3.477	0.002	0.775	1.364
TOTAL S-PEOPLE	3.084	2.051	0.266	1.503	0.145	0.718	1.390
TOTAL S-GOVERNANCE	−1.022	3.039	−0.087	−0.336	0.740	0.550	1.770
TOTAL S-MOBILITY	6.641	2.850	0.527	2.330	0.028	0.595	1.689
TOTAL S-ENVIRONMENT	−0.784	3.053	−0.056	−0.257	0.799	0.606	1.654
TOTAL S-LIVING	9.267	3.193	0.658	2.902	0.008	0.594	1.689
	NUMBEO						
	R	R^2	Adjusted R^2	Standard error of estimation		Durbin-Watson	
	0.826	0.683	0.571	9.02363		1.798	
Constructs	Unstandardized coefficients		Standardized coefficients	*t*	Sig.	Collinearity statistics	
	B	Standard error	Beta			Tolerance	VIF
(constant)	28.688	2.684		10.688	0.000		
TOTAL S-ECONOMY	−6.657	4.720	−0.382	−1.410	0.177	0.254	3.940
TOTAL S-PEOPLE	−11.201	8.754	−0.515	−1.279	0.218	0.115	8.683
TOTAL S-GOVERNANCE	8.183	7.158	0.370	1.143	0.269	0.178	5.610
TOTAL S-MOBILITY	11.476	13.843	0.456	0.829	0.419	0.062	16.218
TOTAL S-ENVIRONMENT	−9.453	10.054	−0.344	−0.940	0.360	0.140	7.158
TOTAL S-LIVING	−14.010	10.730	−0.556	−1.306	0.209	0.103	9.722
Non-participative QoL rankings							
	MERCER						
	R	R^2	Adjusted R^2	Standard error of estimation		Durbin-Watson	
	0.895	0.801	0.682	19.01765		2.132	

(continued)

Table 3 (continued)

Constructs	Unstandardized coefficients		Standardized coefficients	*t*	Sig.	Collinearity statistics	
	B	Standard error	Beta			Tolerance	VIF
(constant)	57.624	14.176		4.065	0.002		
TOTAL S-ECONOMY	−26.848	10.198	−0.661	−2.633	0.025	0.315	3.171
TOTAL S-PEOPLE	16.332	21.215	0.258	0.770	0.459	0.177	5.656
TOTAL S-GOVERNANCE	−16.989	20.102	−0.329	−0.845	0.418	0.131	7.641
TOTAL S-MOBILITY	−12.433	33.536	−0.206	−0.371	0.719	0.064	15.505
TOTAL S-ENVIRONMENT	−10.205	35.709	−0.169	−0.286	0.781	0.057	17.559
TOTAL S-LIVING	10.345	36.561	0.183	0.283	0.783	0.048	20.960
	EIU						
	R	R^2	Adjusted R^2	Standard error of estimation		Durbin-Watson	
	0.970	0.940	0.821	8.86136		3.133	
Constructs	Unstandardized coefficients		Standardized coefficients	*t*	Sig.	Collinearity statistics	
	B	Standard error	Beta			Tolerance	VIF
(constant)	56.819	15.351		3.701	0.034		
TOTAL S-ECONOMY	−16.470	6.239	−0.641	−2.640	0.078	0.337	2.969
TOTAL S-PEOPLE	−6.719	19.544	−0.199	−0.344	0.754	0.059	16.913
TOTAL S-GOVERNANCE	1.464	14.661	0.047	0.100	0.927	0.091	10.996
TOTAL S-MOBILITY	3.293	32.506	0.106	0.101	0.926	0.018	54.803
TOTAL S-ENVIRONMENT	−19.501	40.087	−0.428	−0.486	0.660	0.026	39.024
TOTAL S-LIVING	−0.075	36.870	−0.002	−0.002	0.998	0.018	56.016
Final models							
Participative QoL rankings							
	EUROSTAT						
	R	R^2	Adjusted R^2	Standard error of estimation		Durbin-Watson	
	0.867	0.751	0.691	4.14986		1.519	
Constructs	Unstandardized coefficients		Standardized coefficients	*t*	Sig.	Collinearity statistics	
	B	Standard error	Beta			Tolerance	VIF
(constant)	90.494	1.111		81.432	0.000		
TOTAL S-ECONOMY	−7.039	2.025	−0.567	−3.477	0.002	0.775	1.364

(continued)

Table 3 (continued)

TOTAL S-PEOPLE	3.084	2.051	0.266	1.503	0.145	0.718	1.390
TOTAL S-GOVERNANCE	−1.022	3.039	−0.087	−0.336	0.740	0.550	1.770
TOTAL S-MOBILITY	6.641	2.850	0.527	2.330	0.028	0.595	1.689
TOTAL S-ENVIRONMENT	−0.784	3.053	−0.056	−0.257	0.799	0.606	1.654
TOTAL S-LIVING	9.267	3.193	0.658	2.902	0.008	0.594	1.689
	NUMBEO						
	R	R^2	Adjusted R^2	Standard error of estimation		Durbin-Watson	
	0.826	0.683	0.571	9.02363		1.798	
Constructs	Unstandardized coefficients		Standardized coefficients	*t*	Sig.	Collinearity statistics	
	B	Standard error	Beta			Tolerance	VIF
(constant)	28.914	2.017		14.336	0.000		
TOTAL S-ECONOMY	−3.430	3.175	−0.197	−1.080	0.293	−0.622	−0.235
TOTAL S-PEOPLE	−4.083	4.278	−0.188	−0.954	0.351	−0.658	−0.209
TOTAL S-ENVIRONMENT	−14.316	5.096	−0.520	−2.809	0.011	−0.759	−0.532
Non-participative QoL rankings							
	MERCER						
	R	R^2	Adjusted R^2	Standard error of estimation		Durbin-Watson	
	0.895	0.801	0.682	19.01765		2.132	
Constructs	Unstandardized coefficients		Standardized coefficients	*t*	Sig.	Collinearity statistics	
	B	Standard error	Beta			Tolerance	VIF
(constant)	59.767	4.923		12.140	0.000		
TOTAL S-ECONOMY	−28.183	6.760	−0.694	−4.169	0.001	−0.867	−0.744
TOTAL S-GOVERNANCE	−13.261	8.584	−0.257	−1.545	0.145	−0.723	−0.382
	EIU						
	R	R^2	Adjusted R^2	Standard error of estimation		Durbin-Watson	
	0.970	0.940	0.821	8.86136		3.133	
Constructs	Unstandardized coefficients		Standardized coefficients	*t*	Sig.	Collinearity statistics	
	B	Standard error	Beta			Tolerance	VIF
(constant)	55.750	2.593		21.503	0.000		
TOTAL S-ECONOMY	−16.678	2.830	−0.649	−5.893	0.001	−0.876	−0.912
TOTAL S-ENVIRONMENT	−21.326	5.016	−0.468	−4.252	0.004	−0.783	−0.849

Also, the dimension of smart people seems also to be a good construct for increasing the citizen's perception of QoL (*p*-value close to 0.1). By contrast, the smart governance and the smart environment are not significant constructs for increasing the citizen's perceptions of QoL.

Regarding the NUMBEO QoL model, results show that only smart environment is the only significant attribute in the model (*p*-value under 0.05 and close to 0.01) and show a low and negative influence into the model.

As for the MERCER QoL model, results show that smart economy is a significant attribute of the model with a *p*-value under 0.01, whereas s-governance is close to be significant because its *p*-value is near 0.1. In any case, both of these attributes present a negative influence in the QoL ranking.

Finally, in the EIU QoL model, results indicate a high significant influence of both the smart economy and the smart environment in the QoL ranking, since the *p*-value in both cases is lower than 0.01. Also, both attributes show a negative influence in the analyzed QoL.

Discussions and Conclusion

The growth of SCs has sought the improvement of the QoL of their citizens through the intensive use of ICTs and the implementation of new governance models for improving citizen involvement in public decisions. Based on sample SCs and NSCs in the European context, this chapter provides insights into the existence of a link between SCs and higher QoL and the expected link between smart dimensions and citizen's QoL.

Findings indicate that only sample SCs are those ranked in the QoL rankings. NSCs do not appear in any of the QoL rankings used in this study, which makes one think that the promise of the advent of SCs for increasing the QoL is true. This finding is clearer and more consistent with the results obtained in the selected objective QoL rankings. Therefore, the main question here is: are there other different aspects in the city different from their intensive use of ICTs that could have the same impact on the citizen's perception of QoL in the city? So, future research could analyze this issue in a different context to obtain significant findings.

Regarding the influence of each smart dimension on the QoL, findings point out that smart economy and smart environment are the smart dimensions with a higher significant impact on the citizen's QoL across the different QoL rankings. Nonetheless, both of them seem to have a negative influence on it (see the results for participative rankings—EUROSTAT and NUMBEO—and for non-participative rankings—MERCER and EIU).

These findings seem to be different for particular national settings of European countries. A prior study in Spain (Centre of Innovation of the Public Service & IE Business School, 2015) indicates that the smart environment is relevant for public administrations and it could also be a factor that could have an impact on citizen's perception of QoL. However, in our research, the smart environment dimension is a significant factor in the NUMBEO and EIU QoL rankings and both of them indicate a negative impact on the citizens' QoL.

In addition, road congestion has reached extreme levels in major cities in the world, and it seriously affects the QoL of the citizens (Pacheco et al., 2018). Indeed, the mobility problems into the cities are a relevant issue for smart cities (Centre of Innovation of the Public Service & IE Business School, 2015), which are forcing public agencies to adopt strategies to address city mobility problems (Chow, 2018). Nonetheless, citizens seem not to assign great relevance to smart mobility because it is only significant for the EUROSTAT QoL ranking. Perhaps this results indicates that smart mobility initiatives are not all about technology and ICT, except for the case in which the smart mobility initiative enhances the operations of other sectors of the city (then technology and ICT are central) (Peprah, Amponsah, & Oduro, 2019).

In brief, it is possible that our findings be context-dependent and more studies could help to gain a deeper knowledge on this issue. Therefore, future research could analyze the aim of this chapter in different national settings in identifying trends according to some variables like administrative culture, political settings, e-participation models, and so on.

In addition, prior and recent research have demonstrated that Spanish citizens and university students have a poor preoccupation of the municipality in the areas of smart economy and smart governance (Centre of Innovation of the Public Service & IE Business School, 2015; Vázquez, Lanero, Gutiérrez, & Sahelices, 2018). This negative perception could explain why the public policies of the city management in smart economy practices are not valued by citizens as a piece of their QoL. Perhaps higher government transparency could help to overcome this negative perception.

Also, although prior research and smart practitioners of SCs advocate new and collaborative governance models (Rodríguez Bolívar, 2018a, 2018b, 2018c; Yeh, 2017), our findings indicate that, in general, smart governance does not have an impact on the citizen's perception of QoL. In fact, findings only indicate a negative and significant impact of smart governance on the citizens' QoL in the MERCER QoL ranking (see Table 3). This finding confirms recent research in which, paradoxically, smart governance was the factor that university students less associated with QoL (Vázquez et al., 2018). In this regard, future research should investigate whether citizens are promoted and ready to participate in city management as well as the incentives they have to cooperate with local governments in the city management.

Also, city governments could allocate financial resources to improving a culture of open participation in the city and to making information and technological tools available to citizens for increasing their participation in public affairs. So, future research should focus its attention on the components that could help citizens to change their perception regarding smart governance and its link with the increase of the QoL in the city.

Finally, our findings indicate that smart living is the most significant dimension for influencing the citizen's perception of QoL. This finding is only presented in the EUROSTAT QoL ranking and it confirms recent research in which respondents to a questionnaire recognized smart living as one of the most valued dimensions for their QoL (Vázquez et al., 2018). As the smart living dimension is a very broad concept, future research should analyze the components that have a higher impact on the citizen's perception of QoL (culture and leisure facilities, health conditions, housing quality, and so on).

In brief, SCs seem to fill the expectations of citizens to increase their QoL. Nonetheless, citizen's perceptions of higher QoL seem to be based on both the outcomes achieved in the city and their impact on their lives. In this regard, perhaps the knowledge that citizens have on the concept of SCs and their dimensions could be seriously questioned (Centre of Innovation of the Public Service & IE Business School, 2015). It could influence their perception regarding the smart dimensions and their contribution to increasing their QoL perception. This way, future research could also analyze this issue to understand better the components of the citizen's perceptions of QoL and how city governments in SCs can implement public policies to increase this perception.

Annex

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Part IV
Technology and Management

Smart Cities in the Era of Artificial Intelligence and Internet of Things: Promises and Challenges

Amal Ben Rjab and Sehl Mellouli

Abstract The concept of smart cities is rapidly gaining momentum and worldwide attention as a promising response to different challenges of urban development, such as: lack of natural resources, pollution, traffic congestion, deteriorating infrastructure, economic decline, etc. This concept is driven, among other elements, by technology, and technology is growing so fast. The growth of technology has led to the emergence of new solutions that will transform our societies, as connected objects, self-driven cars, drones, and robots. These technologies can be used in every sphere of a city such as: urban problem-solving, natural resource management, real-time data processing, or predicting crimes, etc. However, these new technologies can pose new social, ethical, and legal challenges that can affect the society. In this chapter, through an extensive literature review of two key technologies used for smart cities development that are the Internet of Things (IoT) and Artificial Intelligence (AI), we identify the opportunities and the challenges that cities may face when adopting these technologies.

Keywords Smart cities · Artificial Intelligence · Internet of Things · Smart City opportunities · Smart City Challenges

Introduction

Currently, the world's population is growing at a rapid pace where more than 50% of the world population lives in cities (Chourabi et al., 2012; Ferraz & Ferraz, 2014). This situation can create tremendous pressure on every aspect of urban living, and pose several significant challenges pertaining to environmental and social sustainability (Ferraz & Ferraz, 2014) such as: poverty, criminality, pollution, deteriorating infrastructure, lack of resources, traffic congestion, or economic decline (Chourabi et al., 2012; De Paz, Bajo, Rodríguez, Villarrubia, & Corchado, 2016; Hui, Sherratt,

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_12

& Sánchez, 2017; Lee, Hancock, & Hu, 2014; Neirotti, De Marco, Cagliano, Mangano, & Scorrano, 2014). To solve these problems and ensure a sustainable development and a quality of life in complex social ecosystems of urban areas (Kitchin, 2014), the concept of "smart cities" has been proposed (Neirotti et al., 2014; Taylor Buck & While, 2017). This concept has attracted considerable attention in the last years (Chourabi et al., 2012; De Paz et al., 2016; Ferraz & Ferraz, 2014; Hui et al., 2017; Kitchin, 2014; Lee et al., 2014; Neirotti et al., 2014; Taylor Buck & While, 2017) from both science and industry. Despite the definitions proposed in the literature to describe this concept, it is still vague (Harrison & Donnelly, 2011; Hollands, 2008; Solanas et al., 2014).

In fact, with the emergence of information and communication technology (ICT), smart cities have been viewed as intelligent digital ecosystems installed in urban areas (Gabrys, 2014) "that seek the technological advances" (Viitanen & Kingston, 2014, p. 1), such as: AI, IoT, blockchain, and cloud computing to ensure a "new era of optimized smart infrastructural management" (Taylor Buck & While, 2017, p. 503) in order to solve urban problems including traffic management, healthcare, energy crises, and many other issues (Luque, McFarlane, & Marvin, 2014; Nigon, Glize, Dupas, Crasnier, & Boes, 2016; Tang et al., 2015).

Several studies (De Paz et al., 2016; Hui et al., 2017; Nigon et al., 2016; Tang et al., 2015; Viitanen & Kingston, 2014) show that currently the technological infrastructure of smart city can be based on IoT and AI that may represent key elements for smart cities development. In order to understand the roles of these technologies in a smart city development, we discuss in this chapter, through an extensive literature review realized during the period 1990 and 2017, the opportunities and the challenges that cities will face when adopting these two technologies (IoT and AI).

This chapter is organized as follows. First, we describe the opportunities that can be generated by smart cities for a sustainable environment (section "Smart Cities: Opportunities for a Sustainable Environment"). Next, we present the methodology adopted to achieve the literature review (section "Research Methodology"). Then, we discuss the results of the literature review (section "Findings"), and we shed light on the role of AI and IoT in smart cities development (section "Opportunities of AI and IoT in Smart Cities"). Afterwards, we present the challenges that cities will face when adopting these technologies (section "Challenges of IA and IoT in Smart Cities"). Finally, we provide the main conclusions, the limits of this study, and some future thoughts (section "Conclusion").

Smart Cities: Opportunities for a Sustainable Environment

According to the United Nations Population Fund, 2008 was the year when more than 50% of all people, 3.3 billion, are living in urban areas, and this percentage is expected to rise to 70% by 2050 (UN, United Nations, 2008) (where the world population will reach up to a limit of 9.7 billion by the end of 2050). This rapid transition to a highly urbanized population creates several problems such as: air pollution, mental health problems, crime, loss of public space, land consumption, pollution, deteriorating infrastructure, or economic decline (Chourabi et al., 2012; De Paz et al., 2016; Hui et al., 2017; Lee et al., 2014; Neirotti et al., 2014). These problems will create many challenges for the planning and the development of cities (Harrison & Donnelly, 2011). In this context, the concept of "smart city" was proposed as a solution to solve these problems by bringing several opportunities, including (Harrison & Donnelly, 2011; Kitchin, 2014; Luque et al., 2014; Neirotti et al., 2014):

- Reduce resource consumption, notably energy, water, and CO_2 emissions.
- Improve the use of existing infrastructure capacity.
- Improve the quality of life.
- Make new services available to citizens.
- Improve the city's security level.
- Predict natural disasters.
- Provide better visibility of traffic/infrastructure issues.

Hence, the concept of smart city is embedded in the sustainable development of cities (Harrison & Donnelly, 2011). Table 1 summarizes the contribution of smart city in the different areas. These areas cover different aspects of a city from technology to governance.

The focus of this chapter will be on the use of technology that plays an important role in the different aforementioned areas. As stated, IoT and AI are key technologies for the development of smart cities. So, it becomes interesting to know in more details the roles of these two technologies (i.e., AI and IoT) in the development of smart cities.

Research Methodology

In this research, we adopted a systematic literature review (SLR) approach to answer the research question. SLR is considered as "a tool for understanding state-of-the art research in fields related to a technology" (Moreira Nascimento et al., 2018, p. 2). This methodology is also considered as the most used for synthesizing knowledge since it is based on a rigorous and transparent process to identify studies (Beaudry, 2011). In addition, it allows identifying critical knowledge gaps by highlighting the discrepancy between what is currently known, what needs to be known, and what motivates other researchers to close that gap (Webster & Watson, 2002). Then, it can help to create a foundation for advancing knowledge (Moreira Nascimento et al., 2018; Webster & Watson, 2002). Finally, it helps to limit bias, reduce chance effects, enhance the legitimacy and authority of the ensuing evidence, and provide more reliable results upon which to draw conclusions and make decisions. For this, we chose to adopt this research methodology to answer our research question: what are the opportunities and the challenges that cities may face when adopting AI and IoT technologies?

Table 1 Opportunities of smart city

Area	Roles	Sources
Data management	Collect and analyze data in real time; process and anticipate data in real time; improve the interoperability of data	Hashem et al. (2016), Kitchin (2014), Tang et al. (2015), Vanolo (2014)
Transport and mobility	Ensure intelligent transport and improve traffic safety; reduce congestion, noise, and air pollution; optimize logistics in urban areas; provide intelligent parking	Arroub, Zahi, Sabir, and Sadik (2016), Caragliu, Del Bo, and Nijkamp (2011), Dirks and Keeling (2009), Djahel, Doolan, Muntean, and Murphy (2015), O'grady and O'hare (2012), Tiwari and Jain (2014)
Healthcare	Improve health sector by developing smart machines able to propose an advanced analysis to predict disease; provide new remote health services; offer new services to control citizens' health remotely	Atzori, Iera, and Morabito (2010), Dirks and Keeling (2009), Nam and Pardo (2011), Solanas et al. (2014)
Security	Strengthen security and protect the privacy of citizens; detect fraud and crime; strengthen cybersecurity; control and monitor the different urban areas	Canton (2011), Castelli, Sormani, Trujillo, and Popovič (2017), Giyenko and Im Cho (2016), Meana-Llorián, García, G-Bustelo, Lovelle, and Garcia-Fernandez (2017), Ramchurn, Vytelingum, Rogers, and Jennings (2012), Shah and Mishra (2016), Tiwari and Jain (2014)
Economy	Enrich economic and improve productivity; increase investment and innovation level	Caragliu et al. (2011), Giffinger, Fertner, Kramar, and Meijers (2007), Yigitcanlar and Lee (2014)
Education and culture	Improve education policy and personalize education; create new opportunities for students and teachers to use new technologies; promote cultural events and motivate citizen participation in the different cultural events	Caragliu et al. (2011), Dirks and Keeling (2009), Khatoun and Zeadally (2016)
Society	Ensure social integration and improve citizen participation; reduce the poverty level and create new jobs	Yigitcanlar and Lee (2014)
Services	Facilitate the accessibility of several services; improve the quality and create new intelligent services	Patti and Acquaviva (2016), Ramirez et al. (2017), Urbieta, González-Beltrán, Mokhtar, Hossain, and Capra (2017)
Environment urban	Reduce pollution and detect natural disasters; managing natural resources; protect environment and improve surveillance; improving energy efficiency	Caragliu et al. (2011), Li, Yao, Shao, and Wang (2014), Nam & Pardo (2011), Nigon et al. (2016), Rathore, Ahmad, Paul, and Rho (2016), Tiwari and Jain (2014)

(continued)

Table 1 (continued)

Area	Roles	Sources
Public administration and governance	Promote public administration by new intelligent technologies; ensure transparency in government activities; strengthen citizen's participation in political life	Caragliu et al. (2011), Dirks and Keeling (2009), Pereira, Macadar, Luciano, and Testa (2017), Schedler, Guenduez, and Frischknecht (2017)

Definition of Review Scope

In order to define the scope of this literature review, we chose to refer to an established taxonomy presented by Cooper (1988), including six characteristics for literature review: focus, goal, organization, perspective, audience, and coverage.

(a) Focus: It represents the central area of interest to the reviewer.
(b) Goal: It is related to what the author hopes the review will fulfill.
(c) Organization: It represents how literature will be organized. The literature review could be organized by: chronological, concepts, methodology, etc.
(d) Perspective: It represents the point of view of the reviewer in discussing the literature.
(e) Audience: It concerns the groups of people (such as researchers, practitioners, policy makers, general public, etc.) whom the review is addressed.
(f) Coverage: It regards how the reviewer searches the literature and how he makes decisions about the suitability and quality of documents.

The following table summarizes our choices, regarding the cooper's taxonomy about the review scope (Cooper, 1988) (Table 2).

Strategy of the Literature Review

As it was mentioned by Webster and Watson (2002), three steps are particularly important when doing a literature review to select and synthesize the existing knowledge:

1. Define the inclusion and exclusion criteria.
2. Define a strategy to locate and identify the studies.
3. Define a strategy to extract knowledge.

Inclusion and Exclusion Criteria

Four criteria were adopted to select the potential studies. To be included in our literature review, a document must:

Table 2 Cooper's taxonomy applied to our study

Characteristic	Cooper's options	Our choice
Focus	Type of papers involved (methodological, theoretical, practices, applications, outcomes)	All types of paper
Goal	Integration, criticism, research problem	Research problem
Organization	Chronological, conceptual, methodological	Chronological first, conceptual after
Perspective	Neutral, espousal of a position	Neutral
Audience	Groups of people whom the review is addressed	Specialized scholars and decisions-makers
Coverage	Exhaustive, with selective citation, representative, central, pivotal	Representative

1. Propose a conceptual and/or operational definition of the concept of smart city.
2. Focus on IA and IoT use in smart cities context.
3. Be a document published between 1990 and 2017. The choice of 1990 as a starting date is justified by Breux and Diaz (2017) who proved that 1990 represents the emergence date of "smart cities" concept.
4. Include the following types of documents: journal or conference paper, books, and reports. However, memories, theses, and editorials were not retained. The choice to exclude memories and theses is recommended by Beaudry (2011) who indicated that all important scientific contributions in these types of documents should be published in a scientific paper.

Data Sources and Studies Selection

To locate studies, two stages were adopted to look and select articles included in our literature review. Firstly, we preceded by an electronic search by using multiple keywords (see Table 3) in several multidisciplinary databases recommended by a librarian expert at our university: ABI/INFORM Global of Proquest, Academic Search Premier (ASP) of EBSCO, ScienceDirect of Elsevier, and Web of Science. Then, we performed a manual search in Google Scholar. Our search query was based on the thesauruses of IoT and AI generated by the different databases consulted, which do not necessarily give all the keywords of these concepts. So, we recognize that other complementary keywords should have been used to look for broader IoT and AI related studies on smart cities. Such keywords can be, for example: 5G networks, or wearable devices among others.

From this search, we identified 5430 potential studies for our literature review (i.e., 2221 studies presented in Web of Science, 1583 studies presented in ABI/INFORM Global, 647 studies presented in Academic Search Premier, 320 studies presented in ScienceDirect, and 659 studies selected from Google Scholar). The

Table 3 Search queries

Search query n°1	((“Artificial Intelligence” **OR** “Machine Learning” **OR** “Deep Learning” **OR** “Robots” **OR** “Avatars” **OR** “Chatbots” **OR** “Neural Network” **OR** “Fuzzy Logic” **OR** “Learning Algorithm” **OR** “Expert Systems” **OR** “Cognitive Computing” **OR** “Genetic Algorithm” **OR** “Evolutionary Algorithm” **OR** “Expert Systems” **OR** “Evolutionary Algorithm” **OR** “Expert Systems” **OR** “Time Series Forecasting” **OR** “Genetic Programming” **OR** “Symbolic Regression”) **AND** (“Smart Cit*” **OR** “Future Cit*” **OR** “Digital Cit*” **OR** “Intelligent Cit*” **OR** “Sustainable Cit*” **OR** “Knowledge Cit*” **OR** “Ubiquitous Cit*” **OR** “Interconnected Cit*” **OR** “Cyber Cit*”))
Search query n°2	((“internet of things” **OR** “future internet” **OR** “M2M”) **AND** (“smart Cit*” **OR** “future Cit*” **OR** “digital Cit*” **OR** “intelligent Cit*” **OR** “sustainable Cit*” **OR** “knowledge Cit*” **OR** “ubiquitous Cit*” **OR** “interconnected Cit*” **OR** “cyber Cit*”))

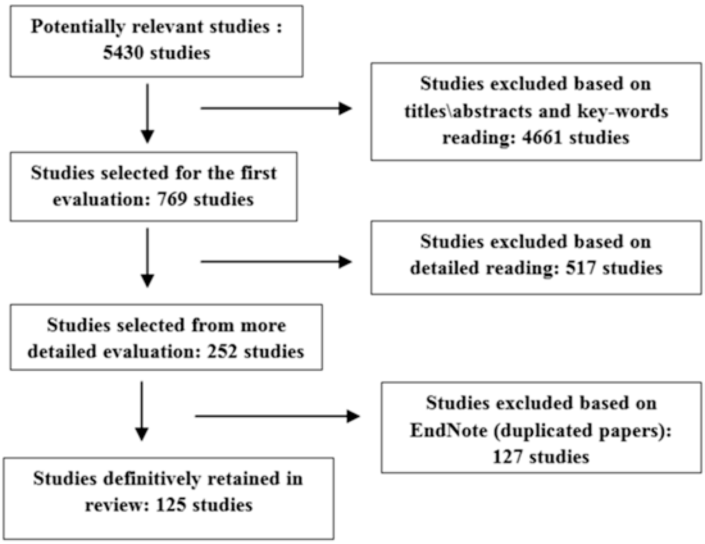

Fig. 1 The flow diagram of the literature review

identified articles (i.e., 5430 papers) were subject to a double screening (see Fig. 1). A first sorting consisted to verify the inclusion and the exclusion criteria from reading the title, the abstract, the keywords, and the introduction of each study. 769 potential articles remained after the first sorting for a thorough analysis. Then, we made a detailed reading of the papers to only retain relevant papers. We eliminated 517 documents and we kept 252 studies. Finally, we removed duplicated papers by eliminating 127 documents and only 125 studies were definitively retained in this literature review as depicted in Table 4.

Table 4 Synthesis of the identified documents

Database	First sort	Second sort	Third sort
Web of Science	120 (15%)	34 (13%)	24 (20%)
ScienceDirect	97 (13%)	25 (10%)	13 (11%)
ABI/INFORM Global	147 (19%)	46 (18%)	23 (19%)
Academic Search Premier	160 (21%)	37 (15%)	17 (14%)
Google Scholar	245 (32%)	110 (44%)	48 (36%)
Total	*769*	*252*	*125*

Knowledge Extraction Strategy

To extract knowledge, we created an Excel sheet that contained each article's reference (i.e., title, authors, year), research type (i.e., qualitative, quantitative, mixed, literature review, survey), scientific contribution (i.e., practical or theoretical contribution), technology used in a smart city, and the summary of each research topic.

Descriptive Analysis of the Included Studies

The distributions of the included studies per type (see Fig. 2) show that the articles represent 92% of included studies, 5% are books, and 3% are reports. The distribution of the included studies per research type (see Fig. 3) shows that the most evoked research type was a conceptual research (with 43% of included publications), 41% were case studies, 8% were literature reviews, 5% were quantitative researches, and 3% were qualitative researches. We can see that the number of quantitative and qualitative studies is low and represents a challenge for future research, since this type of research proposes exact studies based on evidence data (Hunt & Lavoie, 2011). Moreover, the low number of literature reviews reflects an immature literature that needs to be studied (Taylor Buck & While, 2017).

The distribution of research type per year shows that since 2013 there has been a shift in focus toward literature reviews (see Fig. 4) since there are more and more research studies on smart cities.

The distribution of studies per publication year shows that the rate of published studies increased remarkably since 2010 to reach an average of 15 articles per year for the period 2010–2017 (see Fig. 5), which confirms that a large amount of literature around this studied area has been published in the last 10 years (Ishida, 2017).

Findings

Nowadays, the concept of smart city represents a catchphrase that draws increased attention among research institutes, universities, governments, policymakers, and ICT companies (Bibri & Krogstie, 2017; Cocchia, 2014; Dohler, Vilajosana,

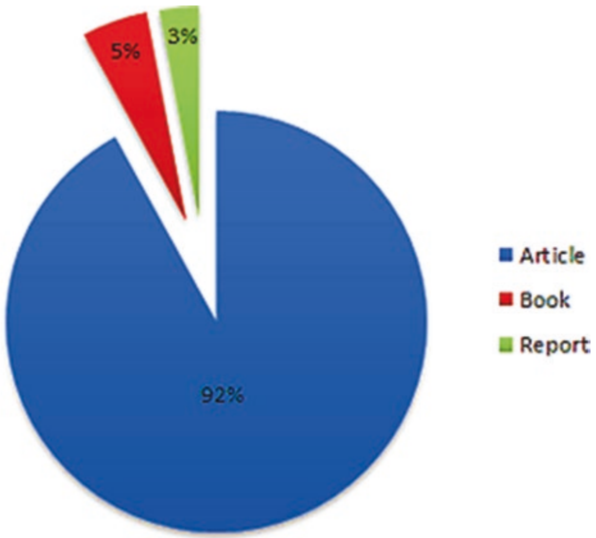

Fig. 2 The distribution of studies per document type

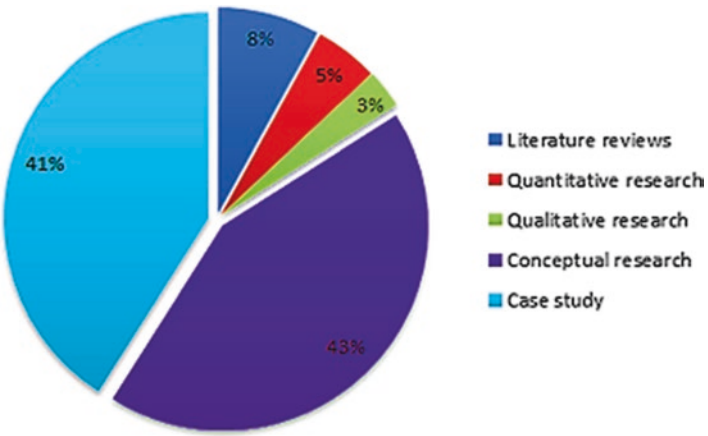

Fig. 3 The distribution of studies per research type

Vilajosana, & Llosa, 2011; Zhuhadar, Thrasher, Marklin, & de Pablos, 2017). It represents a profoundly interdisciplinary field, which makes the concept of smart cities rather vague and complicated (Bibri & Krogstie, 2017; Hause & Hummell, 2016; Hollands, 2008). This literature review shows that there are different views regarding the complexity of this concept. Several authors (e.g., (Bibri & Krogstie, 2017; Gupta & Hall, 2017; Harrison & Donnelly, 2011; Lee et al., 2014; Thrift, 2014)) mention that the complexity of "smart city" refers to the complexity of the term "smartness" that can have multiple meanings such as: safe, connected,

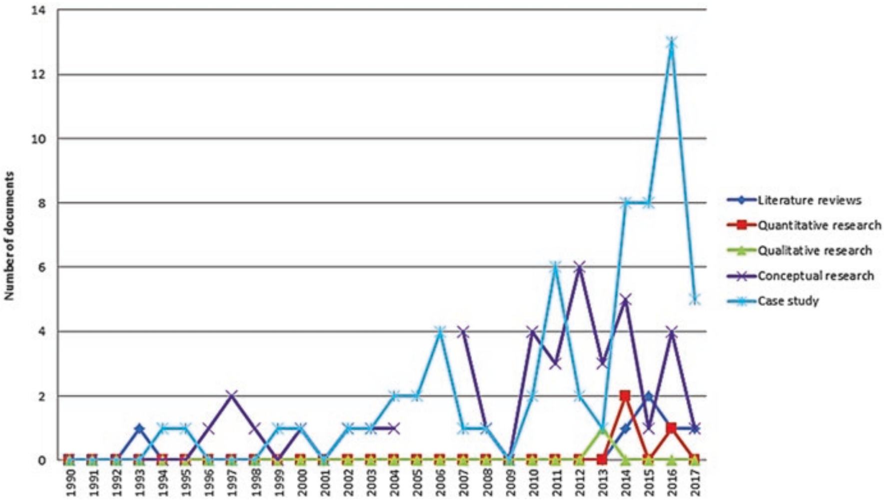

Fig. 4 The distribution of studies per year

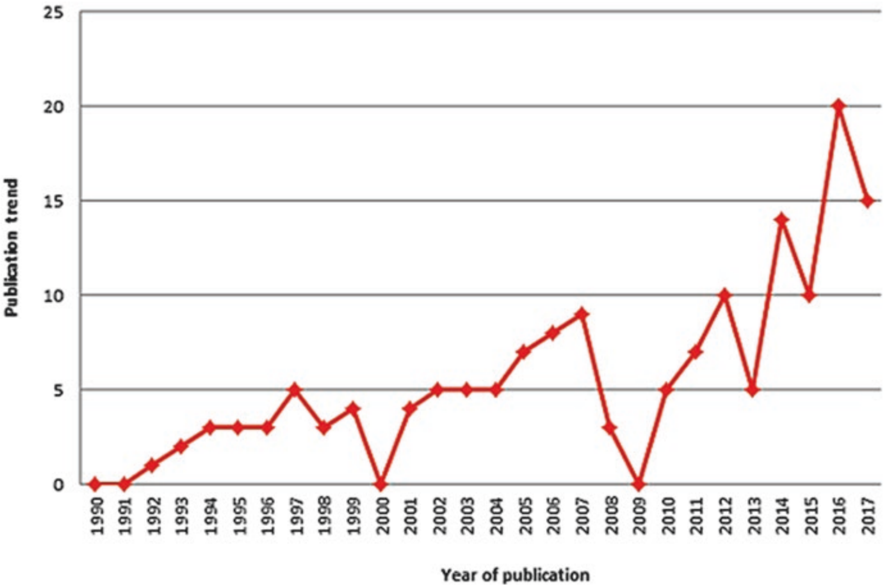

Fig. 5 Publication trend (1990–2017)

intelligent, green, sustainable, etc. In addition, there is not a standard measure to evaluate the smartness level of a smart city (Albino, Berardi, & Dangelico, 2015; Balakrishna, 2012; Jucevičius & Liugailaitė-Radzvickienė, 2014). However, the analysis of the literature shows that there are essentially five levels to characterize

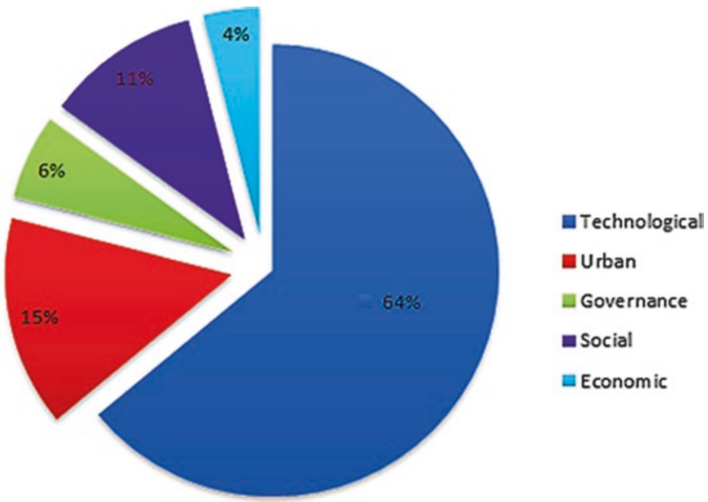

Fig. 6 Bases for assessing the level of smartness of a smart city

the smartness level of a smart city (see Fig. 6): (1) technological level, (2) social level, (3) governmental level, (4) economic level, and (5) urban level. According to our analysis of the literature, we identified that the most cited factor influencing the smartness level of a smart city is the technological level (with 64% of the studies referred to this level to measure the smartness of smart cities). Then, 15% of the studies refer to the urban level, 11% of studies focus on the social level, 6% on governance development, and 4% on economic development.

In addition, the examination of the literature brought out four typologies that have been proposed to conceptualize a smart city:

1. The first typology (Anthopoulos, 2015; Arroub et al., 2016; Balakrishna, 2012; Chamoso & Prieta Pintado, 2015; Giyenko & Im Cho, 2016; Gubbi, Buyya, Marusic, & Palaniswami, 2013; Hui et al., 2017; Jucevičius & Liugailaitė-Radzvickienė, 2014; Mathur & Modani, 2016; Nigon et al., 2016; Patti & Acquaviva, 2016; Sakhardande, Hanagal, & Kulkarni, 2016; Srivastava, Bisht, & Narayan, 2017; Talari et al., 2017; Vakali, Anthopoulos, & Krco, 2014; Vattapparamban, Güvenç, Yurekli, Akkaya, & Uluağaç, 2016) conceptualizes a smart city as a modern city that uses cutting-edge technologies, such as: IoT, AI, and cloud computing to provide an intelligent infrastructure to solve several urban problems. These cutting-edge technologies are defined as new technologies used to perform new functions or greatly enhance functions compared to commonly used technologies (Struecker, Raschzok, & Sauer, 2014).
2. The second typology (Dohler et al., 2011; Hollands, 2008; Lee et al., 2014; Lombardi, Giordano, Farouh, & Wael, 2011; Neirotti et al., 2014; Ojo, Curry, & Janowski, 2015; Pereira et al., 2017) conceptualizes a smart city as a system based on information and communication technologies (ICT) to improve provided services in order to increase the quality of life of citizens.

3. The third typology (Caragliu et al., 2011; Coe, Paquet, & Roy, 2001; Dwivedi & Bharti, 2010) defines a smart city as an entity based on smart governance that aims to develop intelligent strategies to solve social problems.
4. The fourth typology (Aoun, 2013; Roberts & Sykes, 1999) describes a smart city as an entity based on a smart community that aims to optimize environmental resources.

The descriptive results of our analysis (see Fig. 7) show that the literature on smart cities gives a particular importance to the first typology related to the use of cutting-edge technologies. In fact, about 76% of the studies focus on cutting-edge technologies (specifically, 57% of the studies focus on AI, 43% focus on IoT, and 3% focus on cloud). However, 15% of the studies focus on ICT, 5% of the studies focus on governance, and finally 4% of the studies focus on citizens and community. As presented in Fig. 8, the number of publications focusing on cutting-edge

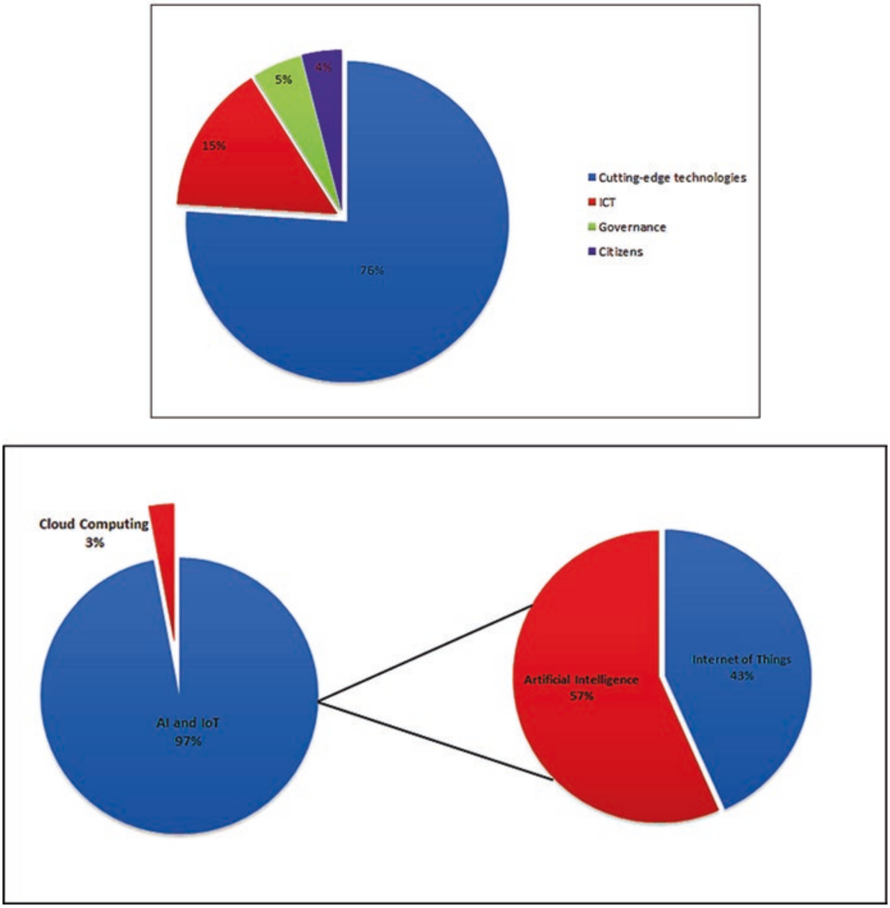

Fig. 7 Typologies of a smart city

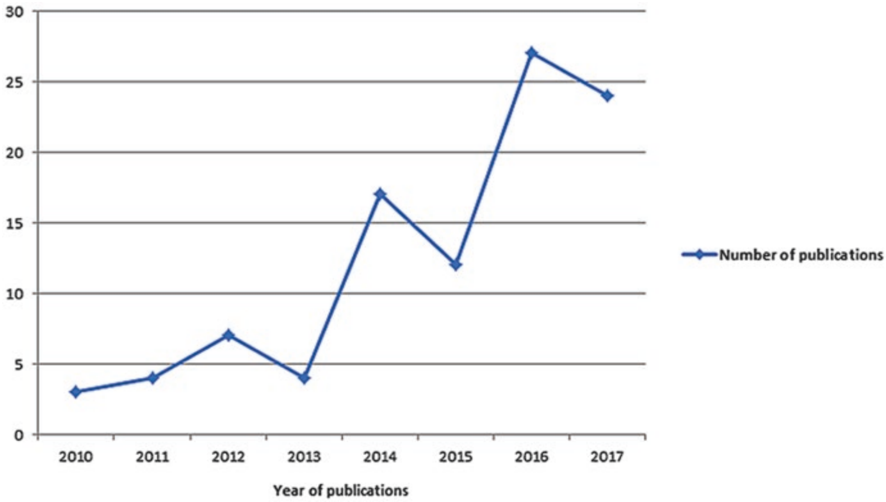

Fig. 8 Publication trend of cutting-edge technologies

technologies is increasing in recent years, which shows the interest of researchers to study this area.

Based on these different results, the next section examines the role of IoT and AI in smart cities.

Opportunities of AI and IoT in Smart Cities

After identifying the cutting-edge technologies that make a city smart, we discuss in this section the roles of IoT and AI in the development of smart cities, and we identify their opportunities and the challenges that have been depicted to ensure a responsible use of these technologies.

The Internet of Things in Smart Cities

What Is the Internet of Things?

Even though the term "Internet of Things" was coined in 1999 (Ashton, 2009), the technologies that enable IoT such as sensor networks existed since the 1990s. Due to the technological advances (i.e., the advances of sensors and cloud technologies, processing and storage capabilities, decreased sensors production cost, etc.), the concept of IoT knew a great growth in the last decade (Borgia, 2014) and it "will transform the real-world objects into intelligent virtual objects" (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014, p. 164). As we can observe, IoT is primarily driven by technological advances but not by applications or user needs (Madakam, Ramaswamy, & Tripathi, 2015). By definition, IoT allows people and things to be connected anytime, in anyplace, with anything, and by anyone, ideally using any path/network and any service (Borgia, 2014). As (Koreshoff, Robertson, & Leong, 2013) states, the technology of IoT refers "to a broad vision whereby things such as everyday objects, places and environments are interconnected with one another via the Internet" (Koreshoff et al., 2013, p.335).

Our analysis of the literature shows that there are several definitions of IoT. These definitions can be grouped into three streams. The first stream of definitions characterizes IoT as an invisible framework to connect a plethora of digital devices with the Internet (Madakam et al., 2015; Mehmood et al., 2017; Ramirez et al., 2017; Talari et al., 2017). The second stream of definitions characterizes IoT as an evolution of the Internet that uses new strategies to ensure the connectivity between different objects (Hui et al., 2017; Zanella, Bui, Castellani, Vangelista, & Zorzi, 2014; Zhuhadar et al., 2017). The third stream of definitions describes IoT as a cutting-edge technology applied on a large scale of urban areas to collect, share, and communicate data between all objects (Gubbi et al., 2013; Hashem et al., 2016; Papadokostaki et al., 2017).

The Role of IoT in Smart Cities

According to our analysis of the literature, we identified that IoT technology is expected to substantially support the sustainable development of smart cities (Vlacheas et al., 2013). It can ensure the connection between geospatial objects (Hui et al., 2017), increase security (Qela & Mouftah, 2012), improve services (Vattapparamban et al., 2016), or optimize natural resources (Gupta & Hall, 2017). The main roles of IoT identified from our analysis of the literature in smart cities are:

1. *Ensure the connectivity between all objects:* Gubbi et al. (2013), Madakam et al. (2015), Ramirez et al. (2017), Sarin (2016), Talari et al. (2017) show that the technology of IoT is used primarily to ensure the ubiquitous connectivity between different objects in the different urban areas.
2. *Real-time data processing:* IoT allows to collect a large amount of data that can be analyzed, stored, and shared (Balakrishna, 2012; Hashem et al., 2016; Tang et al., 2015; Trilles, Belmonte, Schade, & Huerta, 2017). Papadokostaki et al. (2017) illustrated that: "Handling Big Data in real-time represents the Era of IoT" (Papadokostaki et al., 2017, p. 1).
3. *Increasing security:* IoT provides solutions to monitor the movements of people and objects in different areas of a city in order to improve the security level (Vattapparamban et al., 2016; Zanella et al., 2014). However, Su, Li, and Fu (2011) pointed that this role can offense the privacy of people.

4. *Supply management of natural resources:* IoT helps to ensure a proper supply management of natural resources (such as water, energy, etc.) to better control these resources, reduce costs, and improve the economy (Petrolo, Loscri, & Mitton, 2014).
5. *Improve and optimize public services*: Bhatt et al. (2017) and Petrolo et al. (2014) showed that IoT refers to the world of smart connected objects and devices, which allows to improve and facilitate the accessibility of services and create several new intelligent and personalized services.

Examples of Application Areas of IoT in Smart Cities

We looked only at the applications from the reviewed papers. We found five application areas of IoT in smart cities (see Fig. 9): smart home, smart transport, smart healthcare, urban environment, and industry.

Smart Home

It represents the most applied areas of IoT (with 33% of the studies). The technology of IoT is used in smart homes to: improve the security and the surveillance level, provide control of the temperature, detect risks, control all elements in the house, improve convenience and the comfort of the inhabitants, and ensure connectivity between all houses via a neighborhood network in order create a smart community (Bregman, 2010; Darianian & Michael, 2008; Gubbi et al., 2013; Hui et al., 2017; Jaradat, Jarrah, Bousselham, Jararweh, & Al-Ayyoub, 2015; Jin, Gubbi, Marusic, & Palaniswami, 2014; Skouby & Lynggaard, 2014; Su et al., 2011; Zanella et al., 2014).

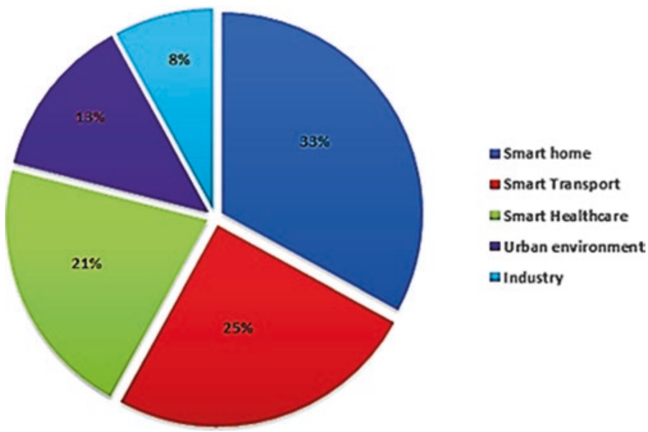

Fig. 9 Distribution of studies per areas of IoT application in smart city

Smart Transport

It represents the second most applied areas of IoT (with 25% of the studies). This technology is used in transport area to: create new routing services, ensure an intelligent tracking of vehicles, provide smart parking (e.g., IoT can track car arrival and departure times, identify empty parking spaces to avoid traffic jams), improve security level through the use of road sensors or RFID (Behrendt, 2016; Bing, Fu, Zhuo, & Yanlei, 2011; Hause & Hummell, 2016; Masek et al., 2016; Ricquebourg et al., 2006), control traffic and ensure a smart display on road conditions to reduce pollution, optimize mobility of people, and save lives (Tsaramirsis, Karamitsos, & Apostolopoulos, 2016).

Smart Healthcare

It represents the third most applied area of IoT in smart cities (with 21% of the studies). This technology allows remotely monitoring patients (24/7) (Su et al., 2011), connect doctors, patients, and nurses via smart device, and each entity can roam without any restriction, collect data about patients' states in real time, locate patients and improve their safety, ensure management of medical emergencies, and management of transfusion information management and real-time health (Boulos & Al-Shorbaji, 2014; Islam, Kwak, Kabir, Hossain, & Kwak, 2015; Su et al., 2011).

Urban Environment

It is the fourth most applied area of IoT (with 13% of studies). Several authors (e.g., (Rathore et al., 2016; Sakhardande et al., 2016; Schaffers et al., 2011)) mentioned that IoT technology can be used to control natural resource systems, temperature, air quality, environment, humidity, weather, rain, carbon dioxide level and harmful gases, noise, and waste management to improve the urban environment.

Industry

It is the last application area of IoT in smart cities context (with 8% of the studies). It allows automating tasks, improving logistics, controlling breakdowns, and providing surveillance in different factories (Sundmaeker, Guillemin, Friess, & Woelfflé, 2010; Uckelmann, Harrison, & Michahelles, 2011).

In short, our analysis of the literature showed the importance of IoT that can be transparently and seamlessly incorporated in a large number of heterogeneous systems (Zanella et al., 2014), and it can play a crucial role in all areas of smart cities. However, several ethical, social, and technical problems can be generated by this technology. Section "Challenges of IA and IoT in Smart Cities" describes the challenges of IoT in smart cities context.

Artificial Intelligence (AI) in Smart Cities

AI is not a new field of research and application. Its beginning is dated to the 1950s (Kurzweil, 2000; Simon, 1996; Turing, 1996), and it began as an inquiry into the nature of intelligence. This technology acquires today a great importance in all areas of smart cities (Nakashima, Aghajan, & Augusto, 2009; Nigon et al., 2016). To better understand the importance of this technology, we will discuss in this section the roles and the applications area of AI in smart cities.

What Is Artificial Intelligence?

Through our analysis of the literature, we have identified two streams of definitions that have been proposed to describe the concept of artificial intelligence: The first stream (Cath, Wachter, Mittelstadt, Taddeo, & Floridi, 2018; Coppin, 2004; Yudkowsky, 2008) characterizes the artificial intelligence as an imitation of human intelligence and human abilities in order to build intelligent machines. The second stream (Aimé, Charlet, Maillet, & Belin, 2015; Lauterbach & Bonim, 2016; Steels, 1993) conceptualizes AI as a simulation between human intelligence and machine abilities in order to solve complex problems. In this context, David et al. (1998) defined AI as the science of building intelligent agents to perform tasks like a human being and reason as a human. In the same way, Coppin (2004) shows that AI is a new area to "involve using methods based on the intelligent behavior of humans to solve complex problems" (Coppin, 2004, p. 31). Despite the diversity of the definitions of artificial intelligence, there is no single universally accepted definition of AI (Cook, Augusto, & Jakkula, 2009). But, we can say that this technology represents a subpart of computer science, concerned with how to give computers the sophistication to act intelligently without being explicitly programmed by using several areas of study and technologies such as voice recognition, image recognition, and natural language processing (Cao et al., 2016; Caragliu et al., 2011).

The Role of AI in Smart Cities

According to our analysis of the literature, we have identified several roles that AI plays in smart cities:

(a) *Ensure an intelligent monitoring:* AI can be used to control and analyze data collected from different sensors to optimize operations (Augusto, Nakashima, & Aghajan, 2010). It can be used, for example, to monitor physical infrastructure or natural resources.
(b) *Ensure an intelligent use of natural resources:* AI allows, for example, to monitor the lighting system by determining the lighting times based on the light levels according to the traffic, which can help to increase energy efficiency,

reduce energy costs, and improve sustainability (Hui et al., 2017; Lauterbach & Bonim, 2016).

(c) *Improve industrial automation:* The use of AI in the form of robots can play an important role in manufacturing industry (Ganascia, 1993) where robots can perform difficult tasks. In addition, AI can be used to detect customer needs, which improve the product quality of a company and increase its economic level (O'Leary, Kuokka, & Plant, 1997).

(d) *Improve the security level:* AI helps to improve the security level in different areas of smart cities. For example, AI can help to predict crimes and improve security in different urban areas (Zhang et al., 2014).

(e) *Improve the interaction with citizens:* The use of different forms of AI as virtual assistants will improve the interactions with citizens (Mathur & Modani, 2016). This technology is already used in different messaging applications such as Messenger, Slack, or WeChat (Shawar & Atwell, 2007).

(f) *Ensure spatiotemporal reasoning:* Augusto et al. (2010) mentioned that AI technology can ensure a spatiotemporal reasoning. For example, a heating system can detect whether a human is present in the room or not to react appropriately and add the temperature to a comfortable level, thereby improving the economy and comfort of citizens.

(g) *Dealing with big data:* AI helps to model, analyze, and transform a large amount of data into reliable information (Cao et al., 2016; Nigon et al., 2016; Pérez et al., 2014), which can improve the quality of the decision-making processes.

(h) *Anticipate needs and adapt services:* AI helps to anticipate need which makes it possible to personalize different services (Ramchurn et al., 2012).

(i) *Ensure an intelligent network:* Castelli et al. (2017), Zhuhadar et al. (2017) mention that AI allows to model, analyze, and predict data in real time without any human intervention.

(j) *Ensure a behavioral modeling:* AI can be used to guarantee a behavioral modeling of data in real time to improve, for example, cybersecurity or increase environmental security (Augusto et al., 2010; Skouby & Lynggaard, 2014).

Applications Areas of AI in Smart Cities

We looked only at the applications from the reviewed papers. As depicted in Fig. 10, the most used area of IA is healthcare (with 26% of studies), then, smart home (with 16% of studies), government (with 12% of studies), learning (with 10% of studies), and security (10% with studies).

1. **Smart Health:** The use of AI in healthcare provides several opportunities to solve real-world healthcare problems (Acampora, Cook, Rashidi, & Vasilakos, 2013; Baxt, 1995; Desouza, 2001; Koh & Tan, 2011; Szolovits, 1982; Zang, Zhang, Di, & Zhu, 2015). For example, it can ensure a correct diagnosis, a precise analysis, an exact prediction of diseases (as cardiovascular disease, cardiac events, etc.), and an efficient treatment of hospital data (Patel et al., 2009;

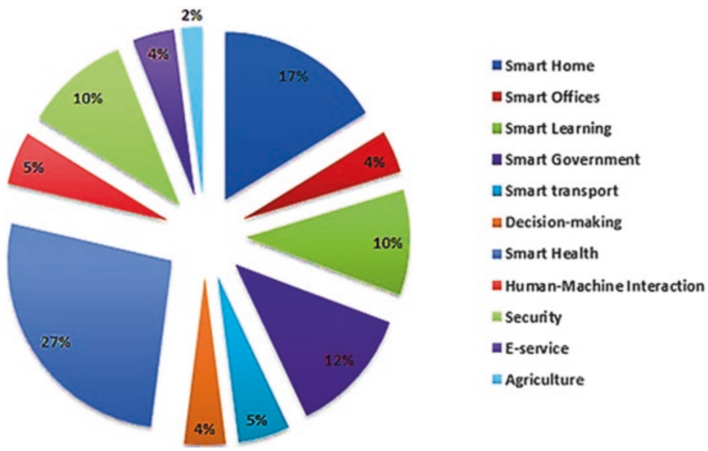

Fig. 10 Distribution of AI application areas in smart city

Speight, Elliott, Jullien, Downer, & Zakzrewska, 1995). This technology can also help to determine an intelligent analysis of complex medical data to provide an effective prediction of diseases (Crawford et al., 2000; Grossi, 2006;Patel et al., 2009; Speight et al., 1995), to identify and predict the chemical carcinogens (Lette et al., 1994; Rosenkranz, Mitchell, & Klopman, 1985), and to improve data analysis in different clinical scenarios (Patel et al., 2009; Speight et al., 1995).

2. **Smart Transport:** AI is used in transportation systems to solve several problems and ensure an intelligent transport (Dias, Bellalta, & Oechsner, 2015; Liebig, Piatkowski, Bockermann, & Morik, 2014; Tsaramirsis et al., 2016). For example, AI is used to: develop autonomous cars (Giyenko & Im Cho, 2016), predict traffic risks and congestion zones (Dias et al., 2015; Mathur & Modani, 2016), ensure an intelligent parking management, develop intelligent solutions to reduce accidents, etc.
3. **Smart Home:** The use of IA makes homes smarter and able to anticipate our actions and our preferences (Augusto, 2007; Augusto et al., 2010; Cook et al., 2003; Li, Da-You, & Bo, 2004; Qela & Mouftah, 2012; Ricquebourg et al., 2006; Robles & Kim, 2010; Skouby & Lynggaard, 2014; Srivastava et al., 2017). This technology allows, for example, to inform a resident when it is time to take its medication, alert the hospital if the resident has fallen, closing the water, or turning off the oven, etc. Hence, AI will render homes intelligent and able to adapt to the needs of the habitants (Cook et al., 2003).
4. **Smart Government:** AI is used by governments to provide intelligent and personalized services in order to ensure a smart public administration (Adadi, Berrada, Chenouni, & Bounabat, 2015; Chun, 2007; Coe et al., 2001; Harsh & Ichalkaranje, 2015; Pereira et al., 2017; Schedler et al., 2017). The use of AI in governments will improve, for example, participation, transparency, efficiency,

accountability, and inclusion to ensure an effective government (Mahapatra, Sharma, Trivedi, & Aman, 2012).

5. **Smart Learning:** AI integrated into different education systems will help to improve the education level, make classrooms smart, support teachers, and students with the use of virtual assistants that can play the role of "tutor" for students, automate the different administrative tasks, and provide personalized help (Heller, Proctor, Mah, Jewell, & Cheung, 2005; McArthur, Lewis, & Bishary, 2005; Mikulecký, 2012; Holmes et al., 2019; Shi et al., 2003; Xie, Shi, Xu, & Xie, 2001).
6. **Security**: The use of AI can improve the security level in different area of smart cities. This technology integrated in different objects can provide capabilities to monitor urban areas through the analysis of movements and the prediction of crimes (Cao et al., 2016; Castelli et al., 2017; Dragomir, 2017; Ramchurn et al., 2012), ensure surveillance of device networks to detect cyberattacks and to improve cybersecurity (Sharbaf, 2018), or secure physical sites such as parks or museums.
7. **Smart Offices:** AI is integrated in different devices such as: robots, cameras, or sensors to make these devices able to support office activities and help in carrying out daily tasks to improve quality of work (Augusto et al., 2010; Mikulecký, 2012; Mizoguchi, Nishiyama, Ohwada, & Hiraishi, 1999).
8. **Human-Machine Interaction:** The use of AI in the form of virtual assistants allows to improve human–machine interactions (Hill, Ford, & Farreras, 2015; Mahapatra et al., 2012) through the discussions with humans in real-time to answer their question, Cleverbot (Hill et al., 2015) and ELIZA (Natale, 2019).
9. **Agriculture:** The deployment of robotics in agriculture area ensures soil preparation, seeding, fertilization, and harvesting (Hollingum, 1999). In addition, the use of AI algorithms can ensure the production of the best combination of soils for better plant management, or the detection of plant diseases, plant protection and control (Murase, 2000). In addition, the use of AI in the form of sensor-equipped drones enable the immediate detection of theft, risks, and anomalies through the collection and analysis of data in real time (Aitkenhead, Dalgetty, Mullins, McDonald, & Strachan, 2003).
10. **Decision-making:** With the emergence of big data and open data, AI can be considered as a helpful tool in decision-making. It can improve the effectiveness of decision-making processes and reduces error rates (Cao et al., 2016; Cortés, Sànchez-Marrè, Ceccaroni, R-Roda, & Poch, 2000) by analyzing data and simulating the future without any human intervention.
11. **E-service:** E-services refer to the use of AI to develop personalized services and creating intelligent services based on intelligent interactions (Lu, Ruan, & Zhang, 2007).

Despite the importance of AI and IoT and the opportunities that they bring to societies, cities may face many challenges related to AI and IoT. These challenges will be discussed in the next section.

Challenges of IA and IoT in Smart Cities

Challenges of AI in Smart Cities

According to our analysis of the literature, we identified several social, legal, and ethical challenges related to AI (Bostrom, 2017; Hawking, Russell, Tegmark, & Wilczek, 2014):

1. Social challenges: The use of AI allows to imitate human behavior and to perform several difficult tasks. However, several researchers raised the problem of unemployment where the robots will replace humans in doing certain jobs (Bostrom & Yudkowsky, 2014; Brooks et al., 1996; Coppin, 2004).
2. Legal challenges: Currently, there is no legal framework that organizes the responsibilities of AI (Bostrom, 2017; Brooks et al., 1996). For example, "will an autonomous car be responsible of an accident?" (Gurney, 2013). Thus, O'grady and O'hare (2012) found that with the emergence of artificial intelligence, robots will become the future residents of smart cities. So, "what is the status of these residents?"
3. Ethical challenges: They can be considered as one of the most challenging for cities (Bostrum, 2014; Frankish & Ramsey, 2014; Hawking et al., 2014). In fact, AI can be able to: imitate human brain, analyze human behavior (Brundage, 2015), trace people and make facial recognition (Bostrom & Yudkowsky, 2014), or even create dependency of people to AI applications (Coppin, 2004), which influence the confidentiality of human privacy and will pose several ethical questions.

Recognizing that these challenges represent a huge challenge, it is important to note that future development of AI can bring more complicated challenges. In this context, several authors (Bostrom, 2017; Bostrom & Yudkowsky, 2014; Bostrum, 2014; Frankish & Ramsey, 2014) indicated that with the next evolution of AI that will be a strong AI, we will witness several existential risks (Brundage, 2015), where Yudkowsky (Yudkowsky, 2008) illustrates that: "A powerful AI could overwhelm any human resistance" (Yudkowsky, 2008, p. 9).

Challenges of IoT in Smart Cities

Through our analysis of the literature, we have identified several challenges related to IoT (Sarin, 2016; Sundmaeker et al., 2010):

1. Ethical issues: With the increasing number of connected objects, that will be expected to reach between 26 and 50 billion globally by 2020 (Sundmaeker et al., 2010), IoT can be used to control citizens and communicate their confidential data. So, one of the crucial questions to which IoT has to answer is: "What

extent privacy is protected?" *(*Jin et al., 2014*)*. For example, several confidential data can be collected by different sensors and that can be shared with other sensors or with other third parties without consent.

2. Security issues: Several authors (Mehmood et al., 2017; Vattapparamban et al., 2016) mentioned that 70% of IoT devices in a smart city were at risks of attacks due to sufficient vulnerabilities such as: free permissions or access, inadequate software protections, or weak encrypted communication protocols.
3. Epistemological and socio-technical issues: Freedom control, authority, independence, automatism, adaptability, and integrity represent major challenges of IoT (Saleh, 2017). For example, connected cars can integrate online data from other protocols that can configure data of the car, share data about the condition of the car, and could even give access of the car to third parties automatically and independently of the driver.

Conclusion

Currently, urban performances depend not only on a city's infrastructure but also increasingly on technological infrastructure. The present chapter aimed to identify the role of the key technologies (i.e., IA and IoT) for smart city development through a literature review. These technologies are used to improve urban infrastructure, optimize natural resources, ensure public safety, optimize and personalize public services, etc. But they also pose several ethical, social, technological, and legal problems different from one city to another, according to: the technological infrastructure of smart cities, economic development, priorities, political structures, legal framework, etc.

To ensure a proper use of these technologies, some governments adopted several strategies, such as: the European Union who created a "European Agency for Robotics and AI" to control the use of AI (Cath et al., 2018). In addition, the United Kingdom called for the development of new regulatory frameworks to organize the use of IA and IoT (Fiander & Blackwood, 2016). As well, the White House and the European Parliament published a report outlining their visions on how to prepare the society for the widespread use of several technologies (as, the artificial intelligence) in order to ensure a "good AI society" (Artificial Intelligence, 2016). However, these reports do not provide an overarching political vision and long-term strategy for the development of these technologies.

For this, we propose as future work, three main research avenues. First, we extend our literature review by using complementary keywords for IoT and AI to have a better overview on the studies about the use of these two technologies in smart cities. Second, through this literature review, we think that it is important to define a new integrative framework to deal with the challenges of AI and IoT in smart cities. Such framework will allow us to understand the role and the responsibility of the government and the research community in the development of IA and IoT technologies. Third, we think that it is important to develop a new model to understand how we can get the most out of AI and IoT in order to ensure a responsible use of these technologies to be beneficial to the society.

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Living Apart Together? Discussing the Different Digital Worlds in City Government

Evert-Jan Mulder

Abstract The concept of the smart city is growing in popularity and is receiving a lot of interest worldwide. An important characteristic of the smart city is the deployment and use of ICTs. Although the interest from research and practice for the new "smart cities" is understandable and justifiable, it is important that the broader context of the use of ICTs by city governments is taken into account.

Namely, three different ICT landscapes develop within city governments: information systems (IS) for the back office, the front office, and the smart city. Each of these landscapes has its own dynamic, organizational setting, and added value for the organization.

For the efficiency and effectiveness of the innovation strategy of city governments, it is important to develop an overarching vision and approach to the use of ICTs. In this way, integration of the different landscapes will be guaranteed in the future.

In this chapter, we describe various models that are used to characterize the use of ICTs within city governments, and we present an overarching model for the use of ICTs within the back office, the front office, and the smart city.

We then discuss the added value and the application of an integrated approach from different perspectives.

Keywords City government · Digital world · ICT landscape · Innovation strategy · ICT use by city government

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_13

Introduction

Digital technology is an important driver of the concept of smart city. A smart city is in many definitions a city that uses new digital technology, next to other non-digital technologies, to face urban challenges (Chourabi et al., 2012; Cocchia, 2014; Granath, 2016). In particular, new cyber-physical systems are eye catcher in the implementation of new smart city technologies. This is about heterogeneous and distributed systems, implemented in sector-specific domains (transport, waste, energy, health, housing, etc), collecting real-time data. This way urban processes get datafied and the city becomes a *datapolis*, the modern version of the *polis*—the old Greek word for city (Meijer, 2015).

The emerging smart city or datapolis is a phenomenon that is a part of the digital revolution that is taking place. The current wave of new information and communication technologies (ICTs) like big data, artificial intelligence, blockchain, robotification, augmented reality, and others will cause disruptive change in society and economy (Brynjolfsson & McAfee, 2014; Floridi, 2015; Tegmark, 2017). Smart cities are part of this wider transformation. This phenomenon is already happening in business domains, where ICT driven models disrupt the existing order. Some anticipate that the same will happen in cities. According to Pereira (2018, p. 27): "The interesting aspect of the emerging technologies is that besides challenging existing governance models, they make it possible for new governance models to emerge. The interdisciplinary nature of smart cities and the changes on the complexity of contemporary urban problems make flexible institutional arrangements necessary which are able to deal with context-specific solutions and multi-stakeholders' environment."

The emerging smart city systems are implemented on top of other information systems (IS)[1] that are already in use in the back office and front office of city government. These IS have been implemented in city governments since the 1970s. Back-office IT—without the C of communication, since networking abilities were limited in the beginning—is often associated with silos and IT legacy. Front-office IS are a result of the implementation of the egovernment concept, since the rise of the internet in the 1990s.

The aim of this chapter is to draw attention to the different IS landscapes in city government and discuss an integrated approach, for the sake of an effective and efficient innovation strategy of city government. In this chapter, we will explore the different IS landscapes in city government and their specific characteristics. We want to highlight the different organizational dynamics at work in every landscape, discuss the need for an integrated city operating model and the challenges involved.

[1] In the definition of Boell & Cecez-Kecmanovic (2015, p. 4959): "Of general interest to the field of IS are therefore all aspects of the development, deployment, implementation, use and impact of IS in organizations and society. However, the IS field is not primarily concerned with the technical and computational aspects of IT. What matters to IS instead is how technology is appropriated and instantiated in order to enable the realization of IS that fulfill various actors'—such as individuals, groups or organizations—information needs and requirements in regards to specific goals and practices".

The motivation for this chapter is rooted in our consultancy practice for the Dutch government. During the last three decades, we have been witnessing the rise—and sometimes fall—of digital technologies at different levels of government in the Netherlands, to many known as a frontrunner in digital innovation. As a consultant, we have been involved in back-office IT projects, egovernment programs, and, more recently, smart city programs. Although our argument is inspired by the context of Dutch city government, other city governments face similar challenges.

We continue this chapter as follows:

In the next section, we will explore the various IS landscapes in city government. We will discuss several stage models that have been introduced in the literature on egovernment and smart city. Building on these models, we will present an overarching model, covering all the different IS landscapes in city government.

Then we will discuss an integrated approach. We will present a stylized model of the fragmented IS landscape of city government and will elaborate on the challenges involved in developing an integrated approach.

We conclude this chapter with some conclusions, both for practice in city governments and for further academic research.

Different Technologies and Different Worlds

The digital revolution, including the introduction of smart technologies within cities, is part of a development that has been going on for a quite some time and which here is called the "digital industrial revolution." The introduction of back-office technology and the rise of the internet are also part of this digital industrial revolution. The digital industrial revolution is the fifth, and for now the final, industrial revolution of the last 250 years. According to Perez (2009) and others (Brynjolfsson & McAfee, 2014) this revolution started in the 1970s with the introduction of the computer, followed by the internet and artificial intelligence. It is impossible to tell when this revolution will end and what will be the next revolution. Some speculate it will be about nano and biotechnology, possibly in combination with digital technology (Drechsler, 2010).

In academics, research into techno-economic paradigm shifts is aimed at analyzing this kind of revolutions. According to Perez (2009, p. 6) a technological revolution is defined as follows: "What distinguishes a technology revolution from a random collection of technology systems and justifies conceptualizing it as a revolution are two basic features. (1) The strong interconnectedness and interdependence of the participating systems in their technologies and markets. (2) The capacity to transform profoundly the rest of the economy (and eventually society)."[2]

[2] Perez further explains (Perez, 2009, p. 6) "Thus, a technological revolution can more generally be defined as a major upheaval of the wealth-creating potential of the economy, opening a vast innovation opportunity space and providing a new set of associated generic technologies, infrastructures and organisational principles that can significantly increase the efficiency and effectiveness of all industries and activities."

The concept of technological revolution and techno-economic paradigm shifts is applied—according to our knowledge—only to a limited extent within the discipline of public administration and egovernment. As far as (historical) modeling of the use of digital technology in government is concerned, it is often within a specific generation of technology and the value models related to them. A well-known example is the—older—model of Layne and Lee (2001), which describes the different stages in the evolution of egovernment IS. Another example is the model on smart city stages, presented by the International Electronic Commission (IEC) (2014) (Table 1):

Some other models, like Vintar (2010), Janowski (2015), and Pereira et al. (2018), are more encompassing. Their models of the evolution of digital government address all the use of ICTs in government. Vintar focuses on the technology evolution in the back- and front-office IS, what we call here "digital city," or the use of ICTs both in front and back office. Janowski's model is also about the evolution of the digital city, but focusses on the impact of different technologies. Pereira's model is both about the digital city IS and the smart city IS.[3] All the stages in these models are not linear, but rather iterative.

Table 1 Stage models egovernment and smart city

Egovernment 4-stage model (Layne & Lee)		Smart City 5-stage model (IEC)	
Catalogue	Online presence. Catalogue presentation. Downloadable forms	Measured	Pervasive sensor networks throughout city
Transaction	Services and forms online Working database supporting online transactions	Networked	Node connections through low-cost communications
Horizontal integration	Lower level systems supporting higher level systems. Within similar functionalities	Managed	Real-time analysis and control of city systems
Vertical integration	Systems integrated around different functions. Real one stop shopping for citizens	Integrated	Integration of isolated systems and across cities
		Smart	SaaS-based citizen services, applications, and management tools

Source: Layne and Lee (2001) and IEC (2014)

[3] Adding to conceptual confusion is that some scholars define Smart City as a Digital City. See for example the definition of Toppeta in Chourabi et al. (2012, p. 2290): "A city combining ICT and Web 2.0 technology with other organizational, design and planning efforts to dematerialize and speed up bureaucratic processes and help to identify new, innovative solutions to city management complexity, in order to improve sustainability and livability." Conceptual clarity is needed and will help to understand why there need to be newer concepts developed to understand the smart city dynamics instead of re-using the existing egovernment concepts. See also Meijer and Bolivar (2015) who touch upon the necessity of new conceptualization for the smart city.

Table 2 Stage models digital city and smart city

Evolution digital city		Evolution digital and smart city
Technology evolution (Vintar)	Impact evolution (Janowski)	Governance evolution (Pereira et al.)
Stage 1: Computerization	Stage 1: Digitization	Stage 1: Electronic government
Stage 2: Informatization	Stage 2: Transformation	Stage 2: Smart government
Stage 3: Egovernment	Stage 3: Engagement	Stage 3: Smart governance
Stage 4: Egovernment 2.0	Stage 4: Contextualization	Stage 4: Smart city governance

Source: Vintar (2010), Janowski (2015), Pereira et al. (2018)

Summarized (Table 2):

Building on these models and other literature (Lips, Bekkers, & Zuurmond, 2005; Yildiz, 2007), we have developed an overarching model, covering all phases of digital technology in government. This is a three-stage model: back-office IT systems, egovernment systems, smart city systems. This model aims to reflect all the different kinds of ICTs in use in city government, plus the organizational dynamics involved (Table 3).

We will elaborate on each IS landscape:

Back-Office IS

Back-office systems are about the administrative, management, and office systems in use in city government. They support the efficiency and effectiveness of the operations of city government. Often terms such as "silo" or "legacy" (Bannister, 2001) are used to characterize this technology landscape. These associations already indicate that the application of technology here is not particularly innovative or cross-sectoral. This is not to say no innovation takes place here. In recent years, important new technological concepts have been implemented, such as cloud computing and related models such as SaaS, PaaS, and IaaS.

eGovernment IS

Front-office systems have been implemented since the rise of the internet supporting the egovernment concept. This network technology enables digital interactions and services in the field of G2C, G2B, and G2G (Nixon & Koutrakou, 2017). It also supports open government and open data, mobile government, and when the web turned 2.0, it also allowed governments to go on social media. Implementation of

Table 3 Characteristics different IS landscapes in city government

Label	*Back-office IT*	*eGovernment*	*Smart City*
Time period	1970s plus	1990s plus	2010 plus
Process	Computerization and informatization	Digitalization and communication	Datafication and robotification
Technologies	Mainframes, PCs, client/server	Internet, mobile, platforms	Internet of things, AI, blockchain
Integration	Monolithic	Loosely coupled	Distributed
Domain	Back-office (internal departments)	Front-office (external G2C, G2B, G2G)	Out-of-office (various stakeholders in the city)
Architecture	Organizational level	Organizational + national level	Organizational + city level
Management focus	Business and IT alignment, vendor strategies, IT legacy	Front- and back-office integration, multichanneling, user-centric design	Multi-stakeholders, triple, and quadruple helix
Roles City government	Buyer, implementator, user	Buyer, (user centric) designer, implementator, user	Coordinator, investor, regulator, steward, strategist, connector
Governance	IT Department	Public Services Department	Smart City Department
Data	Structured, descriptive, static	Structured, descriptive, static	Unstructured, operational, real-time
Added value	"More" (efficiency and effectiveness)	"Better" (service and transparency)	"Different" (governance and policy)

Source: Author (2018)

egovernment IS is enabled by national digital infrastructures. In the EU, there is even a cross-border digital European infrastructure. Nonetheless, almost two decades of egovernment history have learned that the anticipated public reform did not happen (Fountain, 2014). In most Western European countries, the existing structures are more or less untouched. We might say that egovernment did not yet deliver, or just partially, on its promise of "one-stop-shopping" or "seamless" government for the citizen.

Smart City IS

The implementation of smart city systems will add another layer to the existing IS landscapes in city governments. In the beginning of the new millennium, ICTs developed by big tech firms like Cisco and IBM were promoted as a solution for the challenges cities are facing: the concept of the "smart city" was born. Since almost a decade now cities worldwide are developing smart city programs, mostly experimenting with these technologies.

Smart city IS are intended to be implemented in different vertical domains (mobility, waste, energy, etc.), creating a "system of systems" (Cavalcante, Cacho, Lopes, & Batista, 2017). That is also why interoperability and governance are so complex because of the open networks, the heterogeneity of the stakeholders, and the unpredictable behavior of actors and systems. City government also has different roles to play in these networks. Besides coordinator of the smart city program, they act as regulator, steward, strategist, connector, or investor (Deloitte, 2015).

The new dynamics involved with the introduction of smart city IS, although perhaps not immediately clear in the beginning stages, will impact the existing city policy and governance models. As a result, there will be disruptive impact on the organization of city government itself. New roles, processes, and jobs will appear and old roles, processes, and jobs will disappear. Without the organizational transformation of city government, it will be doubtful if the use of smart city IS will ever become a real success.

Summarized (Fig. 1):

Discussing an Integrated Approach

Overlooking these different IS landscapes in city governments, the call for a more integrated approach is not a surprise. "Integration" in a general sense, means "bringing together and uniting things" (Wikipedia). According to the British Standardization Institute (BSI) (2014, p. 14) in their view on smart cities: "Smart city leaders should ensure that their city vision includes the need to develop an integrated city operating model, which is focused around citizen and business needs, not just the city's organizational structure."

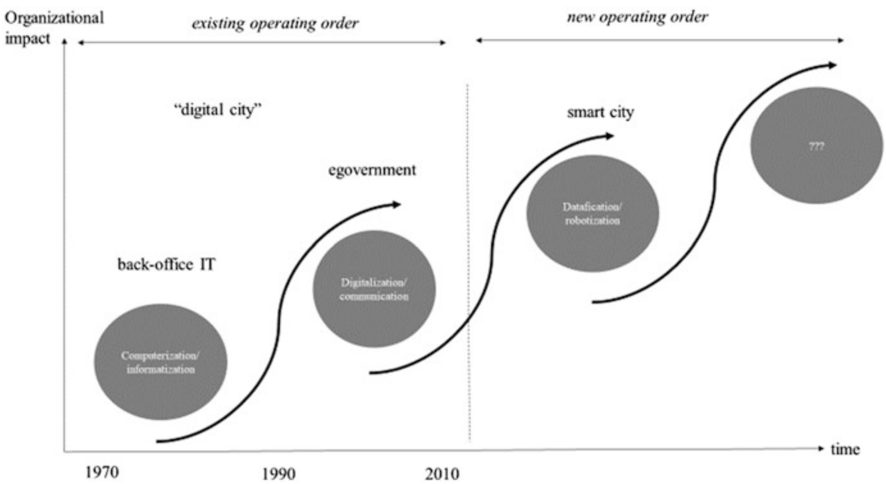

Fig. 1 IS landscapes in city government. (Source: Author 2018)

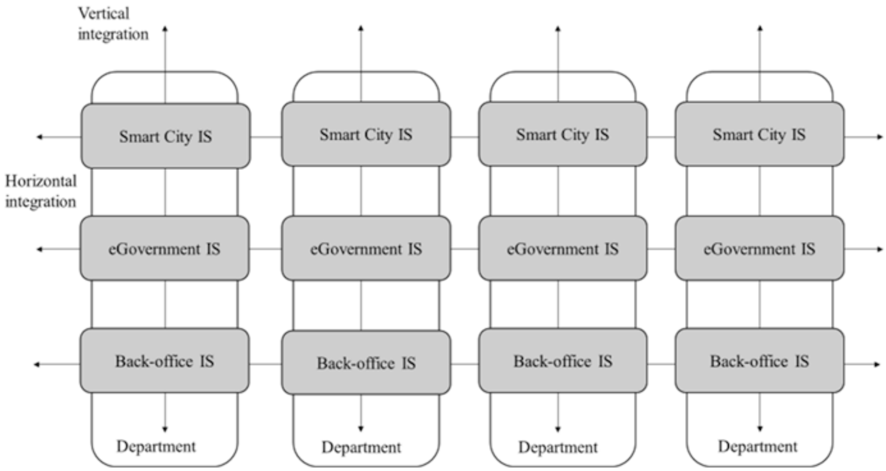

Fig. 2 IS integration in city government. (Source: Author, 2018)

Building on the current operating IS model, adding smart city IS on top, the image of the departmental siloed bureaucracy (Bannister, 2001) almost becomes a 3D-picture: departments having their own back-office IT, egovernment services, and in the near future their own smart city systems. This can be shown stylized as follows (Fig. 2):

IS integration has a vertical and a horizontal dimension. Vertical integration implicates integrating IS from a specific domain perspective (mobility, energy, waste, etc). Besides all the integration challenges in every specific IS domain (smart city, egovernment, back office), there is an overarching integration challenge. For example, how to combine traffic pollution data gathered by smart city IS with administrative data of car ownership and parking policies in the domain of mobility? In other domains, other challenges will exist.

The horizontal integration aims at combining data from the different domains to enable cross-sectoral policy-making and service delivery by city government. Here, every IS landscape also has its own challenges, see the following examples (Table 4):

Especially the introduction of open urban data platforms might be an impactful instrument for integration (Schieferdecker, Tcholtchev, & Lämmel, 2016), combining smart city data and open data as a basis for new models for policy-making and service delivery. For example, it will be interesting to see how predictive models will be implemented in current city policies.

In the remainder of this section, we will discuss IS integration from several perspectives: (1) business value, (2) phasing, (3) funding, (4) mindset, (5) reskilling, (6) standardization, and, last but not least, (7) ethics.

Table 4 Examples horizontal IS integration challenges

IS landscape	*Horizontal integration challenge*
Back-office IT	Enterprise architecture
Egovernment	Portals for one-stop-shopping
Smart city	Urban data platforms

Source: Author (2018)

Business Value

What is there to gain by an integrated IS approach? In the current practice, back-office IT, egovernment services, and smart city programs differ in ICTs at use and their organizational settings. This practice has grown over the last 50 years and has become more or less institutionalized. Nowadays, there is a separate IT department, public services department, and smart city department at work in city government. The lack of an integrated approach leads to the current operating modus, characterized by BSI (2014, p. 14) as: "unconnected, not customer focused, inefficient use of resources (staff, systems), not open to externally led-innovation. no ability to drive cross-system innovation, no ability to drive city scale change at speed."

It is obvious an integrated approach will help to overcome the imperfections of the existing operating order. BSI (2014) has depicted the different elements in such an approach, also summarizing the potential benefits (Fig. 3):

Phasing

Taking into account the challenges modern cities are facing, an integrated IS approach must address these issues for the next phase of IS evolution that cities will enter. In the current phase, smart city initiatives (Chourabi et al., 2012) are mostly about setting up experiments with smart technologies and using the city as a "living lab." Also egovernment and back-office IT are embedded in their own specific dynamics. Egovernment is now witnessing the next step to a more personalized and fulfilling service model for citizens (European Commission, 2017), while back-office IT is tangled up in implementation of cloud computing and other instruments for further rationalization.

In the next phase of smart cities, when it comes to implementation, an integrated approach needs to be applicable. Based on theory of disruptive innovations (Christensen, 1997), we might anticipate two different scenarios. First, a radical scenario, where the existing operating order will be "cannibalized" by the new operating order. This will happen when, for example, the implementation of smart city solutions will make existing back-office processes obsolete. Second, an incremental scenario, including a step-by-step implementation of integration between the different IS.

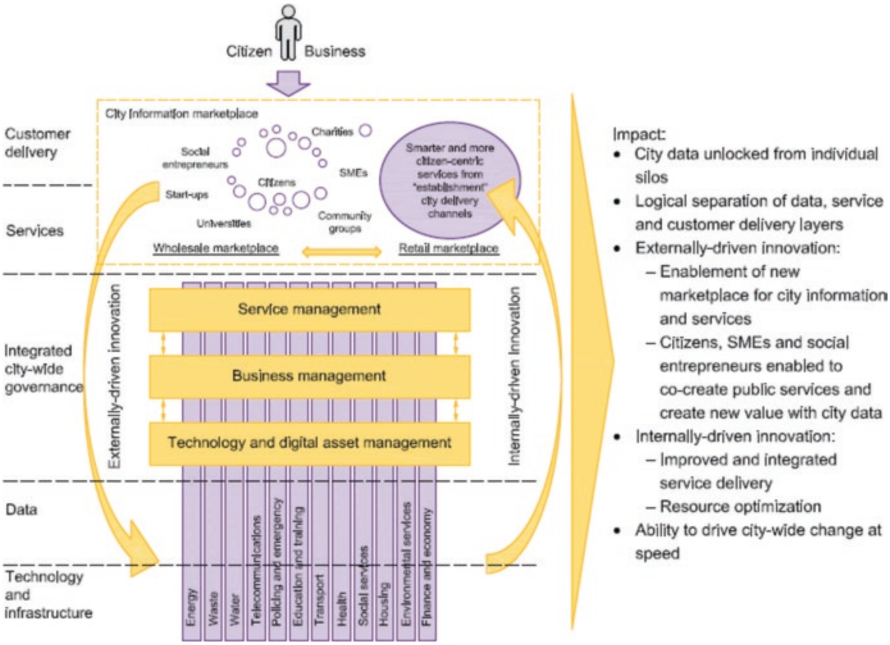

Fig. 3 An integrated IS approach for city government. (Adapted from: British Standardization Institute (2014). Smart city framework—Guide to establishing strategies for smart cities and communities. Department for Business and Skills, UK. p. 15. Copyright 2014 by BSI)

Funding

In the existing order, city government is funding IS in front and back office. With smart city IS, alternative models will evolve, open for (co-)funding by other stakeholders. Since these models are pretty recent, little is known about their actual financial impact and support of smart city IS. The opposite applies, as stated, for the funding models of the current IS in front and back office. As a thumb of rule, ICT budgets are usually spent in a general estimated proportion of 70:20:10. This means 70% budget spending on existing IT legacy, 20% innovations to sustain the existing legacy, and 10% for "new" innovation.

If disruptive innovation becomes more important in cities, these proportions might be challenged and adjusted. Keeping on spending 70% of the ICT budget on existing legacy is not a sustainable model for financing future innovations.

Mindset

The greatest danger of turbulence is not turbulence itself, but to act with yesterdays logic—quote Peter Drucker on "turbulence". Yesterday's logic is omnipresent in the operating model of cities because this model has evolved during the past decades when ICTs were mainly *enabling technologies*. The new smart ICTs are *transformative* technologies (Lips et al., 2005) and will create a double challenge for current leadership, management, finance, and HR. First of all, these functions itself will be disrupted by new technology, and second, these functions have to guide the transformation city governments will face in the future. This will demand a whole new mindset and supporting instruments. For example, the function of financial auditing will be disrupted by technologies like "daily auditing." At the same time, auditors have to develop new frameworks to assess the innovative projects in the name of smart city. These projects do not fit into the traditional business case frameworks applied to "normal" projects because these new projects are more about exploring new models instead of better exploiting existing models.

Reskilling

The coming episode of implementing new ICTs in city government will impact the workforce at least in two ways. First of all, change must be anticipated in the quantity of the workforce. New jobs, like data scientist, will appear, while some jobs, especially administrative ones, will disappear. In the last decade, for example, a lot of administrative jobs have disappeared in banking and insurance. The same jobs are in danger in city government the coming years. Second, the essence of work will change. The World Economic Forum (WEF)/Boston Consulting Group (2018) predicts intensive man–technology collaboration in almost every job, which calls for a *reskilling* revolution as part of the digital revolution. This reskilling revolution will also require new learning models, to deliver on the fast pace of technology change. For city government, an integrated approach is essential on this perspective, to see how staff resources can be optimized and used cross-departmental.

Standardization

Standards, especially open standards, are crucial to guarantee interoperability between the various IS of city government and to avoid vendor lock-in. In the field of back-office IT and egovernment systems over the time of the years, a whole range of standards has been developed, and an adequate governance structure is in place. In the field of smart cities, standards are still under development, over the whole array of vertical domains and all the heterogeneous systems involved, plus the horizontal functions, like, for example, IoT security (Mulder, 2016). These dynamics in standardization are part of the innovative character of the technologies involved. To deal with the uncertainties about technical standards, while at the same time making progress in experimentation and implementation, procurement can be a valuable instrument to address future proof open standards in contracting smart city systems. To prepare for interoperability among all the IS at use in the city government, open standards must be part of citywide IS architecture.

Ethics

Ethics will become a major issue in discussing the use of future ICTs in city government. These concerns include not only privacy and security matters but also concerns about the power of big tech platforms, the transparency of algorithms, or system's autonomy in decision-making. These concerns are much more impactful than the ICTs ethics discussion until now. Computer ethics used to be about matters as intellectual property, privacy, liability, etc. (Moor, 1985). With egovernment, the ethics discussion circled mainly about inclusion (EU, 2017). The introduction of new smart technologies has induced an intense debate about digital ethics, at least in Europe, facilitated by the General Data Protection Regulation (GDPR). Future innovation strategies of cities cannot do without an ethical framework. This is illustrated by the growing need for ethical principles and codes of conduct (Nemitz, 2018). These ethical frameworks need to be included in the IS integration approach.

For example, the cities of Amsterdam en Eindhoven (City Council of Amsterdam and Eindhoven, 2017) in the Netherlands have developed an IoT Charter with principles for data collection and use in the public domain of the city. This charter is uploaded to the national and EU-level.

Conclusions

For the future innovation strategy of city government, it is important to understand the different dynamics in the IS landscapes of back-office IT, egovernment, and smart city. The fragmentation caused by these landscapes does not only hinder efficiency but also cross domain innovation, more citizen focus and citywide change. An integrated IS approach is needed to address these issues to ensure a solid innovation strategy for cities.

For practitioners, including city executives and politicians, and their consultants, it is crucial to acknowledge the importance of an integrated approach of the different IS landscapes in the near future, at the same time allowing room for the current innovations taking place in the different IS landscapes, such as the experiments in smart cities or the implementation of the next-generation egovernment technology.

For academic scholars, there is a new chapter to write about IS integration. Especially scholars from public administration and egovernment, interested in the concept of smart city, should take an integrated approach, since the innovations of the smart city will not take place in splendid isolation. To understand and analyze the future dynamics at work, it is also necessary to develop new concepts.

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Wireless Sensor Network in Smart City Pilots: The Case of Salerno in Italy (from 2015 to 2019)

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Abstract Citizen quality of life can be improved through facilities and services that must be thought to ease citizen interaction with municipal authorities, offices, and structures. Advanced metering infrastructures (AMIs) can be proposed as the backbone of smart city projects. The chapter deals with this topic by describing devices and results of a pilot project designed and carried out by the authors for experiencing the RF 169 MHz wM-Bus in AMI. The AMI was installed in Salerno, an Italian middle city of about 1,40,000 inhabitants and covering a land area of 58.96 km^2. Five public services have been loaded on the AMI to help find the affordability of necessary investments: gas and water metering, car parking management, elder tele-assistance, and pollution measurements. The pilot project has involved the 1.5% of the citizens in 11 city districts. Results provided a great amount of data and information about reliability and efficiency of devices and networks and have been held into account by the authors of the national standard on the shared management of the 169 MHz frequency band (UNI CEI TS 11762:2019). These results let understand that in the next future solutions like those described in the chapter can become products and services available for all citizens.

Keywords Advanced metering infrastructure · Investment affordability · Gas and water metering · Car parking management · Elder teleassistance

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_14

Introduction

In this chapter, the authors present the experience they are having in developing technologies and devices for smart city. In particular, they propose some 169 MHz wM-Bus-based solutions for water metering, public car parking, and elder tele-assistance, which have been designed to be added on the AMI they installed for gas meters. More than an architecture, the smart city is a concept: technologies must improve the well-being of citizens. Citizen well-being and life quality in general depend on lot of factors, which are different in weight and in typology. Some of them like geographical location of the city, dimension, map, modernity of buildings, and structures as well as the civic sense of the inhabitants are not easy to be controlled. On the contrary, other factors like public transportation, traffic and parking management, resource (energy, water, gas), furniture and payment, social care of weakness, pollution, and waste disposal, fully belong to the sphere of responsibility of municipal authorities and companies that provide services on their behalf (David et al., 2012; Lan, Qilong, & Du, 2008). On the basis of similar considerations, in 2015 the Italian National Authority for Gas and Energy started a competition among proposal of pilot projects, to finance those would have had the best fitting with the Authority specifications. Among the winners, the pilot project for the City of Salerno that had the aim of assessing the technical feasibility and the economic sustainability of Advanced Metering Infrastructures (AMIs) in urban context. On the behalf of the Salerno Utility company "Salerno Energia Distribuzione", the pilot project was realized by the authors in cooperation with some ICT companies. The aim of this chapter is describing the research questions generated by the challenge the authors accepted. Two main questions arose: (1) how adding more and more services on the same AMI without saturating the 169 MHz channel bandwidth; (2) how providing a 3D distributed measurement of pollution. As for the former question, the authors adopted the solution of charging the leaf nodes of as much computation as possible. The distribution of computational tasks among peripheral devices, gateways, and central unit required to be accurately designed to avoid that battery powered devices had reduced their life. As for the latter, a solution to the problem was found in embedding a PM10 pollution sensor within electronic devices for water metering. Since the device is based on a cheap optical sensor, a calibration was necessary to evaluate performance and compare with European regulation in the field.

In the following, at first a brief introduction on some technological problems concerning smart city applications will be given. Afterwards, we will widely describe the AMI installed as test bed in the city of Salerno (Italy), where more than 2500 devices are being experienced. Then four devices suitably designed by the authors to fit the specification of water metering utility, public parking, elderly assistance service, and 3D pollution measurement will be detailed.

Finally, results collected in the first year and half of experimentation will be briefly resumed.

Technologies for Smart City

An intelligent city integrates information and communication technology with physical infrastructure in a strategic effort to support efficient services and ensure a high standard of sustainable living for citizens. Tao et al. in (Yin et al., 2015) conducted a survey of intelligent cities and extensively revised existing literature on intelligent city definitions to elaborate a taxonomy from four different perspectives: technical infrastructure, application domain, system integration, and data processing.

From a level perspective, the intelligent city will consist of three levels. After all, physical infrastructure includes all physical services (sensors, controllers, etc.) that already exist as part of an ecosystem in a city. The medium is the IT infrastructure, which involves all IT and communication techniques to interconnect different components. At the top, services are included that involve relevant processes and activities aimed at providing services to the needs of society.

In view of the active research work undertaken on this topic, one should still expect the evolution in the definition of the term "intelligent city" and also the classification of its various dimensions. The classification of these dimensions can take on different forms and compositions through research and development efforts, but only a few elements within these dimensions are currently receiving serious attention from research. Numerous projects have been carried out to update the concept of smart city, while many of them are ongoing and have yet to take place.

Enabling IC technologies are being the main innovators in smart city application. While digital networks provide the basic framework upon which smart cities make information flow, smart meters and all other peripheral devices (Corotinschi & Găitan, 2015; Ferrigno, Morello, Paciello, & Pietrosanto, 2013) lie at the foundation of digital networks. Smart devices and digital networks together allow citizens to reach or to be reached from service utilities. Numerous small and mega projects have been implemented in various efficiency-oriented smart cities. For example, the University of Iasi, Romania, tried to provide a solution for monitoring and managing the heating and electricity systems of a campus, consisting of 11 buildings, for energy efficiency (Mohassel, Fung, Mohammadi, & Raahemifar, 2014). The BCI project in Barcelona Intelligent City, is another, which proposes a solution that adopts open standards and flexible platforms for the integration of multivendor systems (e.g., Wireless Sensor Networks) to ensure the interoperability necessary for the concept of smart city (Gea, Paradells, Lamarca, & Roldan, 2013). The ICeWater project (Kulkarni & Farnham, 2016) studied connectivity problems with water monitoring and management infrastructures. Advanced metering infrastructures (AMIs) have been designed just for this, in the specific field of gas and water. Their infrastructure typically includes: i) meters at the customer site; ii) the communication network between the customer and a service provider; and iii) a management system that makes information available to the service provider.

As for AMIs numerous solutions have been experiencing until now, which adopted different physical channels and different communication protocols (Razavi & Jahed, 2017). Due to its high obstacle penetration capability and scarce power burden, the 169 MHz wM-Bus is emerging as the most convincing physical channel for smart meters, even if the short range (350 m) requires the installation of suitable gateways allowing smart meters to get to the Internet, via either fiber or GSM-GPRS. Bandwidth is constrained in few kBytes, nevertheless it is wide enough for most of smart city services. The low power radio module is compliant with battery powered device autonomy that should last at least 50 years. The wM-Bus, coupled with DLMS-COSEM (Carratù, Ferro, Paciello, Pietrosanto, & Sommella, 2017; Di Leo, Liguori, Paciello, Pietrosanto, & Sommella, 2016; IEC, 2006) protocol, has been founding wide application as the best solution for communication and data structuring in gas field.

The problem is that one gateway would be able to manage the communication with some hundreds of smart RF devices, but the actual density of gas meters in urban area rarely get to this value in a radius of 300 m. When the capability of gateways is not exploited properly, the costs to pay for each meter reading arises so much that gas utilities are discouraged from investing in AMIs. The solution proposed by the authors is that infrastructure cost be shared among more and more services that can be furnished through the same AMI.

While energy meters can trust the power line to be accessible and powered, water metering is quite far from this scenario. Even though some remote accessible solutions are market available, actually the most of installed meters are still mechanical. The major obstacle to wide spread is represented by cost and reliability of the newest measurement devices (i.e., ultrasound-based meters) (Capriglione et al., 2014). To give a solution to this problem, the authors designed and realized an add-on device to extract information from mechanical meters. On demand this device takes a digital picture of the meter display and transmits it to the gateway via 169 MHz wM-Bus radio module. In daily use, the add-on device showed to be reliable and effective, but the wireless channel occupation seemed to be excessive if other services had to be loaded on the same infrastructure. In this chapter is described the solution the authors found to reduce the channel occupation, via onboard OCR. Other services have been experiencing elsewhere, like the public illumination control, but always through proprietary solutions. Air pollution monitoring usually trusts few multisensor stations in the city. The author in this chapter proposes some 169 MHz wM-Bus-based solutions for the elderly assistance, car parking, and pollution distributed monitoring, which have been integrating with gas and water metering services on the same AMI.

The Advanced Metering Infrastructure in Salerno City

Smart metering and sharing of communication infrastructures are very topical concepts that have been the founding principles of the pilot project carried out in the municipality of Salerno, a city of about 1,40,000 inhabitants in southern Italy. Smart metering is changing the relationship between the consumer and the supplier. Both home users and business users today demand that through IoT technologies they be provided with higher quality services without significant cost variation. Service providers, in turn, take advantage of smart technologies for optimized delivery and operational efficiency. From this point of view, smart metering immediately appears as a win-win path, where you can have advantages for both counterparts.

The project pursued two objectives, to which utility companies tend with great interest:

- Meter-to-bill: The possibility to obtain—continuously—useful information for billing from meter reading.
- Meter-to-grid: To be able to intelligently manage the network, by activating remote events that impact both the status and the configuration parameters of the smart devices themselves.

The AMI has been designed to make available the same effective means of communication to several services all characterized by different methods and amounts of data to be exchanged. On the infrastructure basis, an application has been designed to integrate both front and back office functions, with a portal which partners and other players access with different profiles. In addition to the remote reading of water and gas consumption, two other smart device types have been developed specifically for 169 MHz wM-Bus networks: one for the hourly payment of parking on public roads, and the other for remote assistance to the elderly. AMI was designed to collect measurements or events coming from smart devices and make them accessible to utility companies. Suitable gateways, called concentrators, send data to and receive command from a central unit, which is featured with web interfaces suitably designed to allow any control strategy to be executed, and pricing data and commands to be sent to the various devices (see Fig. 1).

The AMI's communication architecture is characterized by hierarchical topology where leaf nodes (smart meters) are connected to master nodes (concentrators). The leaf nodes are battery devices that perform medium or short-range radio transmissions

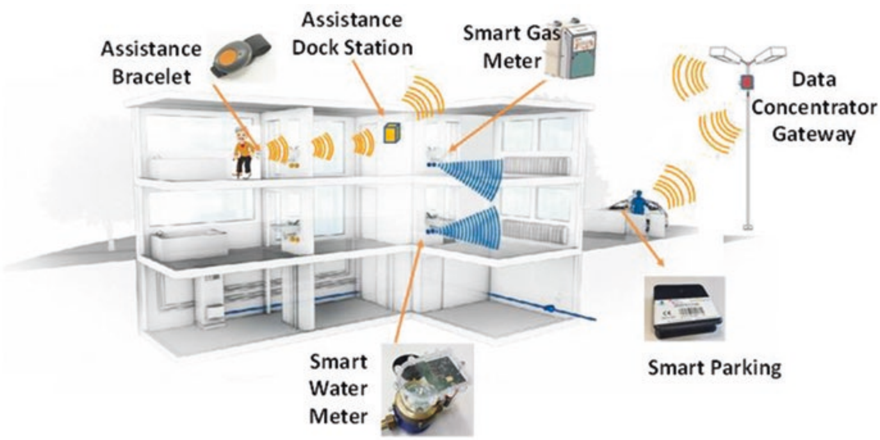

Fig. 1 The architecture of the AMI

in wM-Bus at 169 MHz with a low power consumption, while master nodes add a GSM-GPRS modem (or a fiber cable connection to Internet) to get also long-range communication capability. Each master node stores all data generated from a certain number of leaf nodes and transfers them to a central unit. Usually, unlike leaf nodes, master nodes are either grid or solar cells powered. Both the technical feasibility and the economic convenience depend on the concentration ratio (number of smart devices for each concentrator). Since both such factors can only be evaluated through experiencing urban areas characterized by different densities, at the first stage of the project, 11 city areas were identified, belonging to neighborhoods characterized by different population densities: rural, suburban, urban, and densely urban. Smart devices and concentrators were spread in these 11 city areas, as listed in Table 1 and reported in detail in Fig. 2.

With the objective of assessing the technical and economic feasibility of smart metering, the installation of the concentrators was carried out on available public buildings and sites. The choice of users to install the smart devices was determined by the coverage range of concentrators installed. All citizens were informed of

Table 1 List of smart devices and concentrators installed in the city of Salerno

City area	Address	Density	N° of gas meters	N° of water meters	N° of car parking sensors	N° of elderly assistance	Total N° of smart devices	N° of concentrators
1	Via S. Nicola di Giovi	Rural	3	6	–	–	9	1
2	Via Tramontana	Rural	10	14	–	1	25	1
3	Via Monticelli	Rural	12	12	–	1	25	1
4	Via Postiglione—Ogliara	Suburban	40	47	–	4	91	1
5	Viale degli Etruschi	Suburban	40	56	–	4	100	1
6	Via S. Eustachio	Urban	110	135	–	5	250	1
7	Via Passaro	Urban	90	155	–	5	250	2
8	Via Seripando	Densely Urban	95	90	–	15	200	1
9	Via Gaeta	Densely Urban	125	160	–	15	300	1
10	P.zza M. Luciani	Densely Urban	125	160	100	15	400	2
11	Corso Giuseppe Garibaldi	Densely Urban	350	385	100	15	850	3
Total			*1000*	*1220*	*200*	*80*	*2500*	*15*

Fig. 2 (**a**) The 11 city areas in Salerno map; (**b**) in the zoomed view of area n.7, the position of concentrators and meters

experimentation through the media and those where the smart meters were installed were contacted directly by utility companies.

The final results of the pilot project are analyzed in order to determine:

- The effectiveness of the technology, in particular of the 169 MHz RF physical channel;
- The efficiency of smart metering respect to the traditional methods of reading in terms of economic sustainability and service quality perception; and,
- The compatibility between metering and event-based services (parking and elder assistance) when served by the same communication mean.

These conclusions are going to influence the future policy of public administration and utility companies and so the perspectives of the smart city trends in this ambit.

Furthermore, the national authority for gas and energy is collecting the results of all the similar experiences carried out in the Italian country to update the regulations in the field.

The 169 MHz RF Modules

The infrastructure cost directly depends on the number of "concentrators" installed to cover the whole area of interest. As consequence, the number of smart devices connected to each concentrator (concentration ratio) is the main relative parameter to estimate the cost of services. The wider the coverage range of RF antenna, the higher the concentration ratio, the lower the costs. As for battery devices, transmission power and antenna gain must be compatible with battery capacity to assure long life of devices (Capriglione et al., 2014). The *wireless M-Bus* (EN 13757-4:2013) is suggested by national authority because of its good trade-off between coverage range and power requirements. The transmission mode, over 169 MHz frequency band, allows good coverage range (hundreds of meters in urban area) due to the inherently lower path losses, while the reduced data rates permit higher sensitivity for the receiver, with a consequently reduction of the transmission power at the transmitter or a longer transmission range using the same transmission power (Di Leo, Liguori, Paciello, Pietrosanto, & Sommella, 2015a, 2015b; Ferrigno, Pietrosanto, & Paciello, 2006). The channel bandwidth (7 kHz) is wide enough to allow both uplink and downlink (referred to the central unit). The transmission scheme is that leaf node starts the transmission to the master; after the transmission of the first packet, the master can send commands or requests, in a small reception time window. This means that battery devices can remain in sleep mode as long as they want, thus saving battery. If the leaf node receives a command/request in the reception window, it repeats the last message periodically with a determinate delay, until a new command/request is received from the master. The repetition stops for a termination message, or for timeout. Even though a physical channel like Lora-Wan would allow the same meter reachability and lightly longer coverage range at lower transmission power in uplink, it would not give enough bandwidth for gas meters in downlink, for:

– Configuration of meters.
– Management of commercial parameters (consumption profiles, billing interval).
– Setting of security parameters.
– Meter firmware upgrade.

The Concentrator

The concentrator main task is collecting data from the 169 MHz smart devices and sending them to the AMI central unit.

Concentrator architecture usually includes: i) a power PC board to processing information at application level (DCU functionalities); and ii) as many microcontroller-based radio modules as the number of simultaneous services (gas, electricity, water, etc.…). At DLMS/COSEM protocol level, the concentrator is both client (with respect to smart devices) and server (with respect to the central unit) and grants a transparent end-to-end communication.

The DLMS/COSEM communication profile is implemented by the concentrator also over TCP/IP (developed for GPRS transmission within a public network).

The Central Unit

Data coming from smart devices are indispensable to utility companies for billing and service quality analysis. The central unit must be addressable via the Internet by utilities that need to download data from smart devices and to upload commands.

The central unit consists of three software modules: (1) a JAVA module that implements the DLMS-COSEM protocol to communicate with concentrators through the mobile (GPRS/UMTS) network; (2) a web application developed in PHP that allows users and utilities to send commands to the smart devices and access the stored data; and (3) a MySQL relational database that records all data uploaded by the smart devices.

Also end customers may access their own data by adopting a user-friendly web interface, which makes the underlying communication protocols and objects transparent. About the security features, the Central Access System implements mechanisms for authentication to allow access to the concentrators and utilities.

The data is exchanged among head-end system and concentrators, whereas utilities are encrypted with AES-GCM 128 bit. It is ideal for protecting packetized data because it has minimum latency and minimum operation overhead.

The DLMS/COSEM specifies an interface model and communication protocols for data exchange with metering equipment, including the data encryption and decryption by using a 128-bit AES-GCM algorithm. Moreover, the central unit guarantees the following data security requirements:

– Access control: Authorized users of remote management operations must carry out a double-factor identification (user and machine) to the system, and consumption data are associated to users through pseudonymization techniques managed by the service management company.
– Identification and authentication: The users of the SAC, the automatic processes, functions, or transactions acting against the SAC in the name and role of authorized users, the devices and other information systems that interact with the SAC are identified, authenticated, and tracked.
– System and information integrity.

Smart Add-On for Water Meters

The authors designed a smart device that has to be added on traditional analogue water meters to extract the reading from the photo of the front panel (see Fig. 3).

The method allows the device to be released from any metrological specifications. Its enclosure has been designed to allow easy installation (without detachment) on a good number of meter models and to let the water meter readable by customers. The smart add-on is made of a microcontroller (ARM®Cortex™-M4 32-bit RISC core) based system, featured with the following devices:

– Digital microcamera with a field of view that includes consumption digits and serial number.
– 169 MHz wM-Bus RF module with antenna
– Battery power supply.
– Containment enclosure made of transparent plastic material.

Fig. 3 The smart add-on for water meters

The DLMS-COSEM is implemented in the firmware thus making the device full compliant with the most widespread concentrators. Autonomous power supply (lithium battery with slow discharge) ensures a useful life of the device not less than 5 years. Radio-frequency channel transmission is not subject to government concession, and the transmission distance is higher than 150 m in urban environment. On demand, the photo can be requested by the concentrator.

The meter sends the part of the binarized image that includes the five digits (see Fig. 4). It takes 11 data packets and digits can be either read by human operator or extracted by an off-line OCR software module, which has been integrated with the SAC web interface.

In its last release, the smart add-on firmware implements also an OCR feature that allows the five digits to be online extracted from the image and transformed in a numerical value of the consumption. After the bitmap image has been downloaded from the camera, it can be processed by a six steps procedure (Fig. 4). The main steps of the procedure are: (a) image digitalization through an adaptive threshold; (b) localization and extraction of the decimal counter from the image; (c) measurement and correction of the rotation angle due to installation inaccuracy; (d) digit extraction and separation; (e) cross-correlation of each digit with a suitable pattern which was set up to hold into account also the different lens distortion among the five digits; and (f) numerical evaluation of consumption.

The consumption value takes one packet to be uploaded to the concentrator, but also when only the consumption has been transmitted to the central unit, the photo can still be requested by the utility through a further command.

As for the performance of the OCR feature, a statistic about only 130 readings is available, all made in the last 2 months by add-ons upgraded to the last release. It

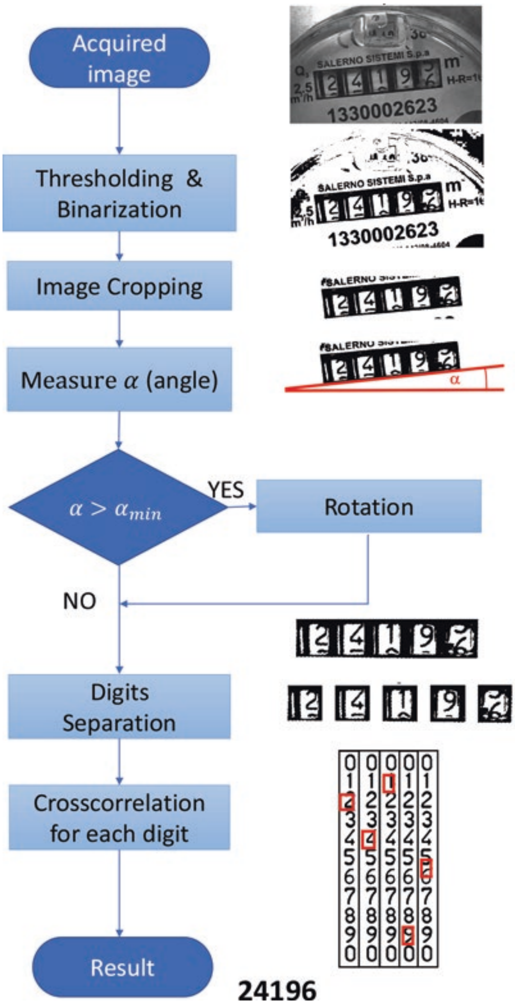

Fig. 4 Onboard OCR procedure

has to be highlighted that: (1) the light conditions should be determined only by the onboard white led because all smart water meters have been programmed to take pictures and transmit packets during the night, while daily times have been reserved to gas meters; (2) the relative position of the add-on respect to the meter display is forced during installation by a suitable hollow on the lower face of the add on, corresponding to a protrusion on the water meter display; and (3) the camera focus is optimal in case of perfect installation.

Nevertheless, in some cases (14% of the total), these three conditions were not fully satisfied. The percentage of correct extraction was 90% and all the remaining 10% belongs to the 14% of installation errors.

Elderly Assistance Service

The multiservice communication infrastructure is used to support an elder tele-assistance service, with the aim to protect the well-being of users (mainly elderly and disabled people), allowing them a more serene stay in their living environment. The realized "tele-assistance" service can generate an alarm for any type of emergency, active 24 h a day, every day of the year (Fig. 5).

The user is provided with:

- A push-button radio remote control (radio-frequency battery device in free loan) to generate the intervention request and for safety the user must wear or carry on the button.
- A dock-station (the sensor for tele-assistance) powered by an electrical source with dual radio communication, towards radio remote control and towards the nearest concentrator, according to the 169 MHz wM-Bus and DLMS/COSEM protocol.

The dock-station is then able to connect to the multiservice.

Concentrator to route the request for assistance to the central unit that collects all data coming from concentrators. Finally, the central unit activates an Automatic Alert Report (through appropriate prerecorded SMS message) in favor of the elder's trustworthy peoples (listed during registration to the service). The dock-station is programmed to send an acoustic luminous signal of the absence of the service, both when the radio link with the concentrator is interrupted and when the concentrator cannot communicate via GSM-GPRS with the central unit. Other similar systems are available on the market, which send SMS messages to registered numbers. All of them require either a Wi-Fi connection or a land/cell phone line. The device proposed by the authors works within the coverage range of an installed concentrator, without requiring direct access to the Internet or a telephone connection.

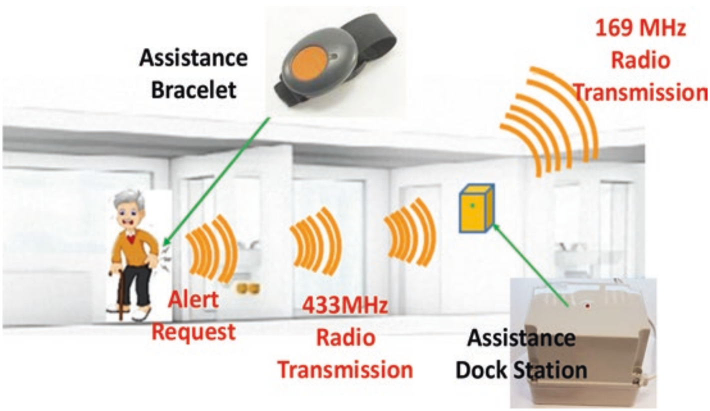

Fig. 5 The smart devices for elder tele-assistance

Tele-Parking Service

The multiservice communication infrastructure is used also for managing the public parking slots (blue strips, gates) in order to improve both the perceived quality of the service (ease of access) and the efficiency of the provider. The tele-management service works thanks to a battery powered device that must be kept in the car by the user: a radio-remote control featured with a button that must be pushed when the car has been parked to communicate its identification code to the nearest concentrator according to the wM-Bus and DLMS-COSEM protocol. The equipment is provided, on loan, to the user at the time of registration at the tele-parking service.

The starting of the parking time is activated manually, by the user by means of the push button; the remote terminal communicates at the multiservice concentrator which provides to route the request to start at the central unit. The request activates the system for charging the service provided. The end of the stay is automatically detected by the loosing of the connection between the remote terminal and the multiservice concentrator, when the car leaves. This condition indicates to the central units the end of service and allows the corresponding payment to be computed. In comparison with the parking platforms present on the market today, based on the adoption of SMS messages and/or smartphone applications, the proposed solution offers the advantage of greater simplicity and speed of access. No position, no expected duration, no information must be given, just a button push. The payment stops with max delay equal to the resolution of the tele-parking (10 min), which is determined automatically by the movement of the car with radio remote control still in ON state since the new spontaneous transmission that is of the addressed type does not receive acknowledgment from an eventual different concentrator visible from the radio-remote control during the movement (Fig. 6).

Fig. 6 The tele-parking device

The user must be sure only to stay in the coverage range of a concentrator. The status of the connection is signaled by a suitable multicolor led, and the average waiting for connection time is about 1 min. The device must always be visible on the dashboard of the car and if the user does not push the button the led remain turned off thus allowing controllers be alerted.

PM_{10} Sensor Prototype

In October 2013, the specialized cancer agency of the World Health Organization, the International Agency for Research on Cancer (IARC), declared "outdoor air pollution a leading environmental cause of cancer deaths." It was also demonstrated that cardiovascular health consequences of exposure to airborne particles could be even worse than those due to pulmonary ones. The IARC evaluation showed an increasing risk of lung cancer with increasing levels of exposure to particulate matter (PM) and even more ultrafine particulate (UFP), among the major components of outdoor air pollution. The European Environment Agency (2017) has recently confirmed that key air quality standards for the protection of human health, including particulate matter (PM) and UFP, are currently not met in many air quality monitoring stations in the European Union. However, instruments for UFP measurement are very expensive and this causes sparsity of measurement points. PM sensors can be, on the contrary, cheaper, nevertheless PM measurement stations are still very few and not widespread in urban areas. Therefore, in order to meet actual and future demand of distributed measurement systems, low cost PM and UFP wireless sensors could be thought to be connected to RF networks that are being today widespread in smart cities. Waiting for a new generation of low cost UFP sensors, the authors tried to connect some 169 MHz wM-Bus wireless prototypes featured with a PM_{10} sensor to the concentrator network in Salerno. PMs are classified in terms of diameter, i.e., PM_{10} has a 10 μm diameter or less. Both $PM_{2.5}$ and PM_{10} particles contain nonvolatile components such as sulfur, heavy metals, and elemental carbon. Primary outdoor sources of PM_{10} are burnt fuel from automobiles, construction equipment, and power plants. The choice fell on PM_{10} because low cost sensors are widespread on the market. The PM_{10} sensor that was integrated with a wM-Bus radio module, like that of the water meter add-on, is the GP2Y1010AU0F manufactured by Sharp and reported in Fig. 7a). Due to the implementation of wM-Bus and DLMS-COSEM protocols in the firmware, the prototype can be easily connected to the 169 MHz network and communicate with a concentrator. As consequence, after its installation at home of some utility customers, near water or gas meter, it will be automatically included in the concentrator white list.

The sensor is based on an optical sensing device which exploits the light reflection (thanks to the inclusion of a suitable infrared light emitter). When the light hits the particulate matter, a phototransistor discloses the presence; the corresponding measure comes out as a voltage signal in the (expected) range 0.9–3.4 V (Fig. 8). The PM_{10} sensor output signal is acquired by the visual add-on thanks to a suitable

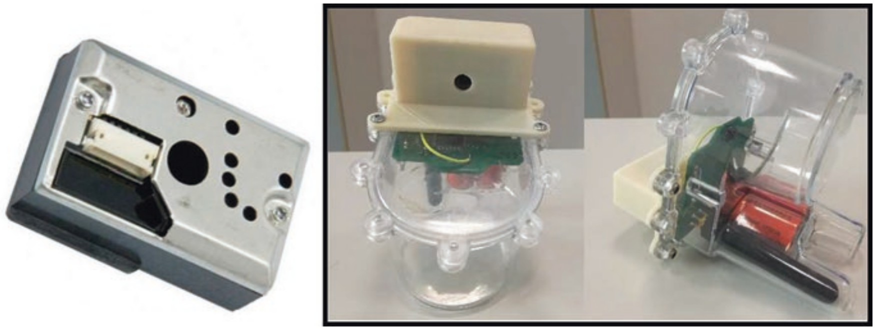

Fig. 7 (**a**) The GP2Y1010AU0F sensor. (**b**) The water add-on like PM_{10} sensor

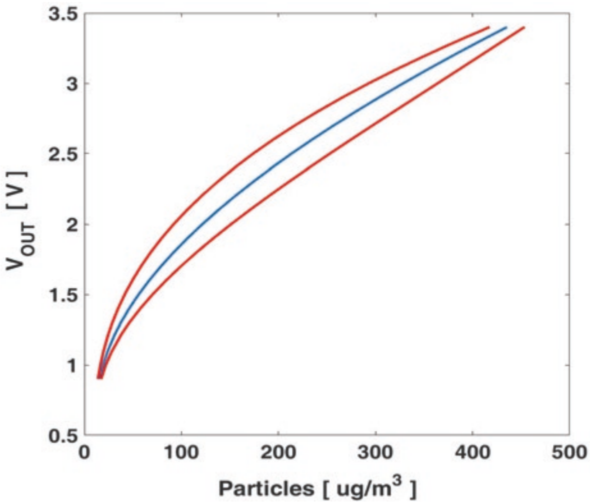

Fig. 8 PM sensor calibration curve (blue line). Red lines represent the uncertainty range

external conditioning circuit. In detail, the circuit drives the PM_{10} sensor infrared diode according to the pulse-driven waveform suggested by the manufacturer: a PWM with a period T of 10 ms and a T_{on}/T_{off} interval respectively equal to 0.32 and 9.68 ms. The single measured value is obtained by averaging 64 consecutive readings from the 12-bit ADC within 1 s. The current consumption during measurement operations is low; the mean value is around 11 mA with a peak of 20 mA.

The result is in Fig. 8. Metrological characteristics of 30 PM_{10} sensors were evaluated according to the procedure suggested in (Rajasegarar et al., 2014; Semple, Apsley, & MacCalman, 2013) in comparison with the Dylos Pro-1100 device as reference instrument. The 30 PM_{10} sensors and the reference instrument were placed inside a hardboard box (internal volume = 1 m^3). A lit cigarette (kept at the middle of the box) was used as PM source during the calibration, whereas the sensors (previously synchronized with time resolution of 1 s) were collecting one sample each

60s. The lit cigarette was left in the box for a total time of 5 h. The PM_{10} sensor outputs got suddenly to saturation; starting from the 150th minute they gradually decreased. By adopting the cubic polynomial fitting suggested in (Semple et al., 2013), the calibration curve has been computed for each PM_{10} sensor. The results are shown in Fig. 9 in terms of mean value and standard deviation within the output range of interest (0÷500 μg/m^3). The PM_{10} sensor uncertainty obtained from the metrological characterization ranges from 5 to 25% of the corresponding reading. The sensors are enough accurate for the implementation of a macroscale 3D model to be adopted for PM_{10} monitoring. The power battery sensors could be spatially distributed like water and gas counters are, thus providing as many as you want PM_{10} measurement points in a three-dimensional space. If the daily PM_{10} concentration single measurements wanted to be used instead for air quality evaluation according to European and national directive (European Parliament, 2008), the requested data uncertainty of 25 μg/m^3 (with 95% confidence level) could not be assured by this cheap sensor. Nevertheless, if a great number of battery powered wireless sensors were widespread in the urban area to be monitored, the output of little sets of near sensors could be averaged to obtain a mean value with uncertainty decreased with $1/\sqrt{N}$, where N is the number of the set. Thanks to this, the metrological performance can be compensated through the average by exploiting the data availability from spatially distributed sensors within the WSN. In detail, the comparison between the worst case for the estimated measurement uncertainty (80 μg/m^3 at PM concentration equal to 230 μg/m^3) and the prescribed data quality (12.5 μg/m^3) leads to a requirement for the number of the sets (N = 50) which could be assured by the WSN in Salerno, where no concentrator has saturated its concentration ratio. Still few prototypes have been installed until now at household level, but an installation campaign is getting start that involves the Salerno very center (City Area N.11), where the need of tree dimension distributed pollution measurements is particularly felt.

Main Results of the Pilot Project

The experimentation in the City of Salerno, started at the end of 2015, in November, is still ongoing. The AMI has been installed between November 2015 and July 2016. It is made of 15 concentrators, which were collocated in 11 city's districts characterized by different densities of customers and different typology of buildings. Two screenshots of the SAC web interface are in Fig. 9. It is possible to note that the network manager profile allows the real-time visualization of the status of meters through the different color they appear on the map. In particular, the green color means that meter transmitted last data within a week, while the yellow within a month and the red one more than a month. It is to be considered that water consumption is requested every 2 months, while gas meters transmit four times a day.

Experimental results have been collecting in the central unit data base and for sake of brevity were summarized in Table 2, in Table 3, and in Table 4. In Table 2,

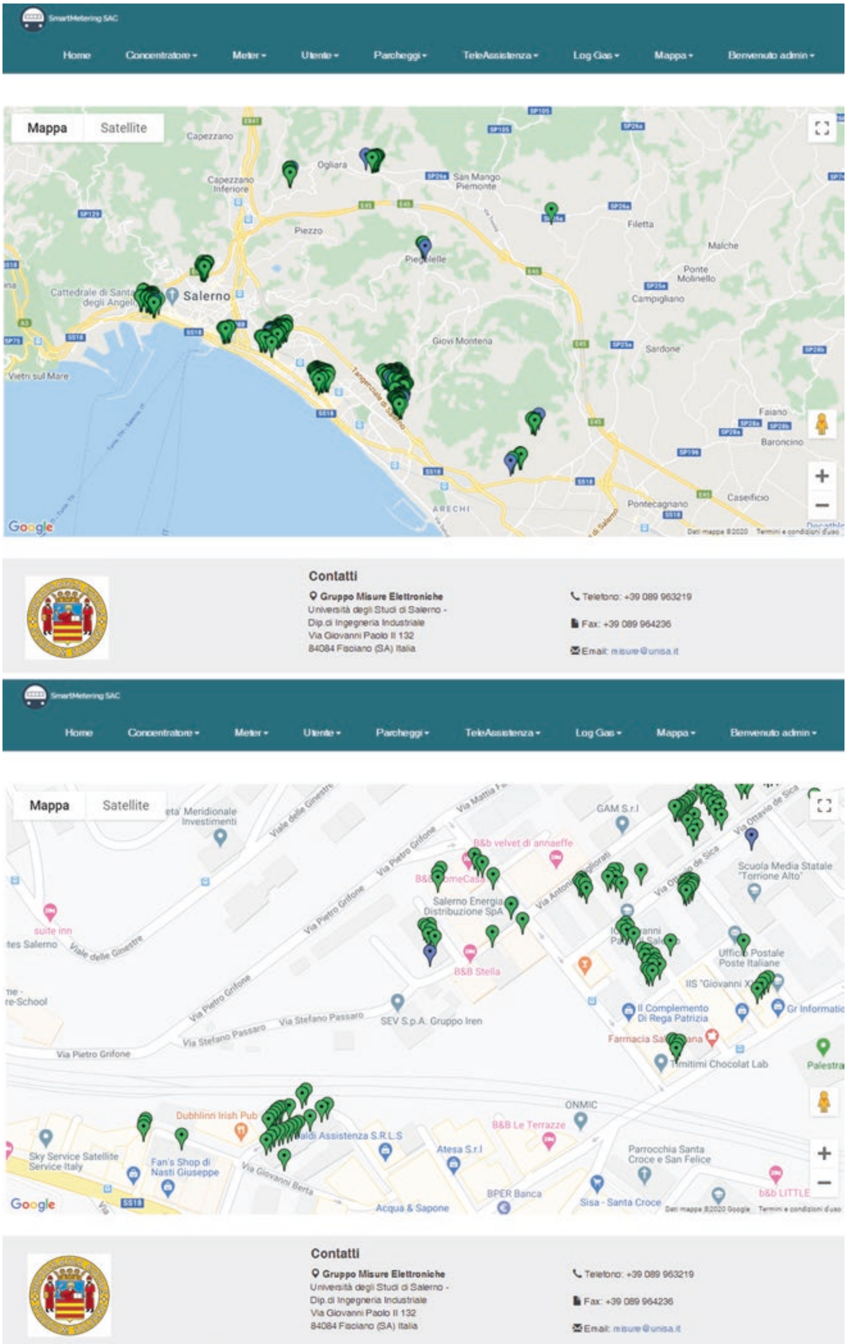

Fig. 9 Two screenshots of the SAC web interface: (**a**) all the map; (**b**) zoomed part of the map

Table 2 Summary of Application requirements

Application	End-points	Uplink			Downlink		
		Periodicity	Dataset (bytes)	Daily load (bytes)	Periodicity	Dataset (bytes)	Daily load (bytes)
Gas metering	1000	3times/day	150	450	1 time/ month	50	–
Water metering	1200	3 times/ day	150	450	1 time/ month	50	–
Parking management	200	6 times/h	50	300	6 times/h	50	3
Health alert	80	Random	50	–	Random	50	–
Electricity metering	20	3 times/ day	150	450	1 time/ month	50	–

Table 3 Performance indices for Gas and Water Meter in terms of Reachability (R) and SAC (A)

Index	Gas R/A	Water R/A
Number of working points at the start	1.400	1.200
Monthly average reachability DAILY rate	91%	89%
Monthly average reachability WEAKLY rate	97%	95%
Reachability rate in the MONTH	99%	97%

Table 4 Performance indices for Gas and Water Meter in terms of Reachability (R) and SAC Availability (A)

Index	Gas R/A	Water R/A
Number of working points at the start	1.400	1.200
Monthly average reachability DAILY rate	91%	87%
Monthly average reachability WEEK rate	93%	93%
Reachability rate in the MONTH	96%	95%

the average data rate of each smart device is reported, both in uplink and in downlink (referred to the central unit). Uplink is periodic only for gas and water meters and concerns consumptions, while for the other services the data flow is unpredictable. Downlink is generally reserved to commands to be sent to devices for either commands of firmware upgrade.

In Tables 3 and 4, the report of reachability at both concentrator and central unit level of gas and water meters is showed at the early and the today stage of experimentation, respectively.

The missing meters are still a few, after 24 months. The value let hope that battery capacity be enough to reach the expected goal of 5 years battery life for the most of devices. The behavior of parking and elder assistance devices has been more difficult to characterize until now because their number is too low to produce significant statistics in so few months. However, the customers questioned by phone by the staff of the utility company, said they were satisfied. These interesting results have been held into account by the authors of the national standard on the shared management of the 169 MHz frequency band (UNI CEI TS 11762:2019).

Conclusions

The AMI designed, implemented, and experienced by the authors in the City of Salerno demonstrated the feasibility of the approach to smart city context. All devices showed to be well designed to provide reliable services to customers. Battery devices exhibited enough autonomy to make the money investment convenient. All devices adopt DLMS-COSEM protocol, which leaves very few points of ambiguity in communication if its implementation is rigorous and complete. The occupation of the channel showed to be compatible with all the needs, also when all the services are fully working. Among these, the highest amount of transmitted data is due to a smart add-on for water meters. However, its newest release strongly reduces the number of packets to be transmitted to the concentrator thanks to an onboard OCR feature that demonstrated very good performance in case of right installation of the device. The device for elderly tele-assistance showed to grant an effective fast service to people that can be either disabled or unused to IoT smart devices. Both tele-parking service and PM_{10} distributed measurement look like being effective, but they will be useful when the RF network coverage will be extended to the whole. Concerning these last, from the calibration emerged that the space distribution of the sensors allowing the measurement uncertainty do not exceed the European standard threshold and are compatible with the AMI architecture. The result of experimentation lets imagine that in the future these devices and infrastructure can be widespread. Battery device future developments will be focused on increasing autonomy and reducing dimension. As for the water smart meter, future efforts will be dedicated to decrease the sensitivity of the add-on device to the installation inaccuracy.

Acknowledgments The experimentation would not have been done without support and contribution of “Salerno Energia Distribuzione SpA” management and personnel.

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Building a Smart City Platform: A FIWARE Example

Peter Salhofer, Julia Buchsbaum, and Michael Janusch

Abstract This chapter describes the architecture of a comprehensive IoT solution entirely based on the FIWARE platform. The application is designed to record data from environmental sensors and to eventually visualize them on a smart city dashboard. Besides solving certain architectural and technical issues, one particular challenge arose from the fact that some of the sensors were assumed to be mounted on public transportation vehicles like busses and trams. It could be shown that the FIWARE platform provides a range of components that allows for building such an IoT platform in a very efficient way.

Keywords Smart City Platform · Internet of Things · FIWARE · Environmental sensors · Smart City Dashboard

Introduction

When it comes to the implementation of a smart city platform, it is hard to find a reference architecture that is concrete enough to be rolled out on an as-is basis. There are various recommendations for such architectures and standards; however, most of them are rather high level and are lacking implementation details (Dustdar, Stefan, & Ognjen, 2017; International Telecommunication Union (ITU), 2015; Nettstraeter, 2012; OneM2M Alliance, 2014; Zanellla, Bui, Castellani, Vangelista, & Zorzi, 2014).

On the other side, one approach that is highly integrated and even provides implementation is FIWARE. It is the result of several EU funded projects with the goal to provide a set of standardized APIs supporting the creation of smart applications in various fields (Publications Office of the European Union, 2011, 2016, 2017a, 2017b). Its mission is "to build an open sustainable ecosystem around

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_15

public, royalty-free and implementation-driven software platform standards that will ease the development of new Smart Applications in multiple sectors."[1]

Currently FIWARE is intensively promoted by the FIWARE Foundation (FIWARE, 2019a) that tries to push the take-up of the FIWARE stack. This stack consists of a broad set of APIs as well as reference implementations of these API, resulting in a huge set of modularized, open-source software components that are grouped in "general enablers." Therefore, FIWARE seems to be one of the most mature reference architectures/implementations for smart city platforms.

This chapter presents the results of a project that implemented an IoT solution exclusively based on these FIWARE components. It is therefore structured in the following way:

- Section "Case Description" describes the use case that was implemented.
- Section "The FIWARE Platform" briefly discusses those FIWARE components that have been used to solve the use case scenario.
- Section "The Implementation" presents the architecture of the final solution.
- Section "Performance" examines the results of performance tests conducted on the actual IoT installation.
- Section "Conclusions" summarizes our findings.

Case Description

The solution presented in this chapter was a prototype for an actual IoT installation that is currently being realized. Thus, while implementing the software, sensors were not in place but were represented either by mockups or by actual makeshift sensors based on a raspberry PI. The general idea was to collect data from various sensors that are mounted throughout a city area. These sensors were supposed to collect the following data:

- Temperature.
- Humidity.
- Concentration of fine particles (PM2.5 and PM10).

All sensor data needs to be stored in a data sink, and the application should provide an easy-to-use dashboard, visualizing the data using geographical maps, tables, and different charts. One long-term goal was to use the collected data combined with external data (e.g., regional weather data) to generate a prediction model for the particulate matter concentration, motivated by its enormous impact on the health of the population (Polichetti, Cocco, Alessandra, Trimarco, & Nunziata, 2009).

The plan was to have some of these sensors mounted on predefined points that were suggested by the environmental department. In order to have the necessary power supply, traffic lights or light poles closest to these points were chosen. On the

[1] https://www.fiware.org/about-us/, last visited October 30, 2019.

other side, some sensors shall be mounted on public transportation vehicles (busses and trams). These mobile sensors also need to report their current position along with the other sensor data. In addition, data transmission should be performed in a way, so that there will be a new sample every 200 m.

The FIWARE Platform

The core of the FIWARE ecosystem is called FIWARE platform. It is a set of public and free-to-use API specifications that come along with open-source reference implementations.

The FIWARE platform is grouped in seven major parts called the "generic enablers (GEs)" (FIWARE, 2019b). Every GE represents a certain aspect of FIWARE services and also provides one or more components along with reference implementations that support the specified APIs. Additionally, there are "domain-specific enablers (DSEs)" that (will) provide components for certain domains like health, energy, and so on. The general enablers are organized as follows:

- *Data/context management*: This contains all components that are needed to store, access, process, and analyze data as part of a smart application.
- *Internet of Things (IoT) services enablement*: Here are all components needed to setup sensor networks and routing sensor data to other GEs.
- *Advanced web-based user interface*: Components to design user interfaces, including geographical information and interactive 3D charts.
- *Security*: Components to add, define, and enforce declarative security.
- *Advanced middleware and interfaces to network and devices.*
- *Applications/services and data delivery*: Components and tools for data visualization, easy generation of mashups, and app-store-like distribution of services and data.
- *Cloud hosting*: Components and tools aiming at providing and managing FIWARE services via cloud infrastructure.

FIWARE used a great variety of different programming languages (C++, Java, Python, NodeJS,…) and environments for developing their reference implementations. Fortunately, the FIWARE community provides docker (Fink, 2014) images for every component, which makes dealing with different runtime requirements relatively easy.

In order to get a basic understanding of the components that were required to get the use case implemented, we will briefly describe them in the following subsections.

The Context Broker: Orion

Probably the most essential API within the entire FIWARE stack is called "context broker" and its reference implementation is called Orion[2] (see Fig. 1). As soon as a system makes use of this component, it can be officially called "Powered by FIWARE".[3] The center part of Orion is a modern NoSQL database called MongoDB[4] that is used as internal data store. This store is accessed via a RESTful interface that implements the Open Mobile Alliance's *Next Generation Service Interface* (NGSI) protocol (Open Mobile Alliance, 2012). Since the underlying datastore is a NoSQL document store, Orion also does not use database schemas and allows for the creation of any type of entity. It supports a simple, URL-based query language that also provides projections and pagination. Thus, in cases where a longer list of only a subset of attributes is needed, this can be easily achieved, which makes Orion a perfect backend for single-page applications.

Besides this, Orion supports multi-tenancy via a simple header field identifying the required tenant (FIWARE Orion Team, 2019). The most important feature, at least when it comes to IoT applications, is Orion's capability to easily subscribe for changes in the data store. In fact, publish–subscribe is the single most important interaction pattern used by the various FIWARE IoT key components. Subscriptions can be made for specific types of entities (e.g., all Busses), for specific attributes of these entities (e.g., get me informed whenever the "location" attribute of any bus changes), or for individual entity/attribute combinations (e.g., get me informed once the "temperature" in Bus 25 changes).

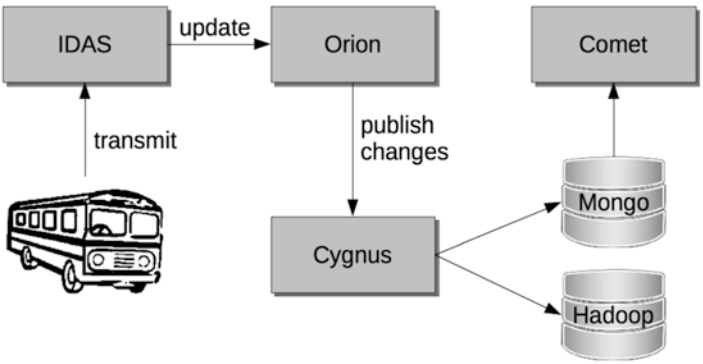

Fig. 1 Flow of sensor data within FIWARE

[2] https://github.com/telefonicaid/fiware-orion

[3] https://www.fiware.org/developers/catalogue/

[4] https://www.mongodb.com/

Backend Device Management: IDAS

For managing the interaction with sensors, FIWARE provides a general enabler called Backend Device Management. Its reference implementation is called IDAS (Ucendo, 2016) and it provides a REST endpoint with the API required for registering sensors and dealing with their data. Before a sensor can be added to the system, in a first step a so-called *service* needs to be created, which serves as the logical endpoint for a group of sensors. Besides this, every new sensor registered with this service gets its own unique *device_id*. Both (the service and the device id) are part of the URI that is used by the sensor to deliver its measurement results. IDAS also takes care of the routing of all incoming sensor data. In FIWARE, all data that is produced by sensors is mapped to attributes of entities. For example, let us assume there is a bus with a sensor mounted to it that periodically transmits its location, the current temperature, humidity, and particle matters concentration. Within FIWARE we can first model the bus as a business object of our application. This will most likely include attributes like license plate, model/make, engine type (diesel, gasoline, natural gas, or electricity), and others. When registering a new sensor device, all its values need to be mapped to attributes of a specific entity stored in the context broker. Thus, whenever a sensor sends a new sample, the corresponding attributes of the entity are updated. As a result, whenever we fetch a bus from the context broker, it will also have attributes like location, temperature, and so on that will always contain the latest sensor results.

Storing Time Series Data: Cygnus

As described in the previous section, IDAS is used to route inbound sensor data to corresponding entity attributes. This makes sure that every entity always represents the most current state of the underlying cyber-physical system. On the other hand, this does not include the availability of historic data, since with every update the previous value of the attribute is overwritten. In order to also keep the previous values of sensor results available, an additional component called Cygnus (FIWARE Cygnus Team, 2017) is required. This component is essentially an extension of Apache Flume (Apache Flume, 2017) that is used to store updates in a persistent storage. It is listening for incoming data that is then forwarded—according to its internal configuration—to one or several data sinks. Possible data sinks are beside others MongoDB, HDFS, and PostgreSQL.

In order to continuously store sensor values over time, a subscription with the context broker is created by Cygnus. This will make sure that whenever a particular property of a specific type of entity is changed (e.g., the *location* property of entities of type *bus*), Cygnus receives this information and sends it to the persistence storage (see Fig. 1).

This architecture allows for a clear separation of live data stored in the context broker and the historical data stored in any database of choice. Having split the task over several loosely and asynchronously connected components allows for high performance and throughput. This can all be achieved without a single line of programming so far.

Short-Term Historic: Comet

Since everything in FIWARE is about REST-based APIs, there is also a component that allows for RESTful access to the historic data sink. The name of this component is Short-Term Historic (STH) and the reference implementation is called Comet (FIWARE Comet Team, 2016). It provides an API for reading historic data produced by the component chain described above, but only supports MongoDB data sinks so far.

Security

None of the components that have been mentioned so far support security. Thus, whenever one has access to these services, there are no restrictions on what can be done. This includes the creation, modification, and deletion of any data or configuration information within the system. Within FIWARE, security is conceptually a separate layer that needs to be put atop the other components. One potential benefit of this architectural decision is that the whole security layer can be replaced by another implementation if needed.

FIWARE's standard security infrastructure is based on OAuth2 (Hardt, 2012) and consists of the following three components (see Fig. 2):

- Identity Management (IdM): Within the OAuth2 protocol, this component is the authorization server, thus all client applications have to register with the IdM. It also provides a REST API and a web-based user interface to create users, roles, and permissions.
- Policy Decision Point (PDP): This service provides authorization by deciding whether the current user is allowed to perform a certain action.
- Policy Enforcement Point (PEP): This is a proxy server that performs the actual authentication and optional authorization checks in interaction with the other two components.

The IdM is the central component of the FIWARE security architecture. Its reference implementation is called Keyrock (Salvachúa & Alonso, 2016), and it is based on OpenStack Keystone (The OpenStack Foundation, 2017b), which in turn is an open-source implementation of the OpenStack Identity API (The OpenStack Foundation, 2017a). It is holding all user information and is a single sign on service

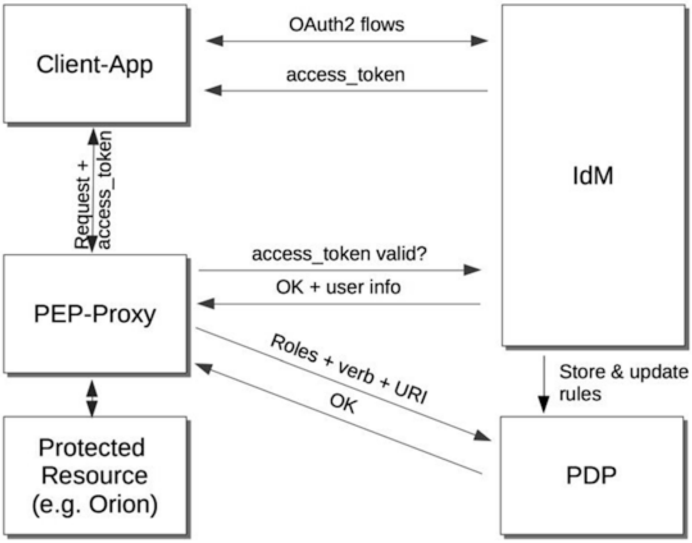

Fig. 2 The basic authorization flow (Salvachúa & Alonso, 2016)

for all components and applications. Thus, applications do not necessarily need to maintain user information (especially no private credentials) and one account can be used for all applications using the platform. It has recently undergone a major refactoring, including additional, yet basic features (like modifying and deleting existing permissions) that had not been present in earlier releases.

The second important security component within FIWARE's security architecture is the Policy Decision Point (PDP) with its reference implementation called AuthZForce (Dangerville, 2017). The role of this component is to authorize access to protected resources. Therefore, so-called *permissions* are created using the IdM, which in the most basic form are combinations of http request methods and URIs. For example, such a rule could grant unlimited read access to all entities stored in the context broker by combining "GET" as http verb and "/v2/entities" as URI into a permission. These permissions are sent from the IdM to the PDP and stored there. These rules are encoded in the eXtensible Access Control Markup Language (XACML) (Rissanen, 2013).

The set of security components is completed by the Policy Enforcement Point (PEP) with its reference implementation called Wilma (Alonso, 2018). The PEP is a very simple proxy server that is placed in front of the service that should be restricted and is acting as the actual *resource server* according to OAuth2. Thus, instead of allowing direct access to a service like Orion, IDAS, or Comet, the client application needs to interact with the PEP proxy instead. The actual authentication and authorization flow is shown in Fig. 2. Before a protected resource can be accessed, the client application has to get an access token by logging into the system using an IdM account. The PEP proxy checks for the existence of this token and then for the validity by querying the IdM. If the token is valid, the PEP proxy also gets the name of the current user and a set of roles that could also be used for full-custom application layer security. This information is cached at the PEP. After this, the PEP makes a query to the PDP to figure out whether this request is authorized. Only if the PDP agrees, the original request is sent to the protected resource.

It is important to note that the PEP has to register and authenticate itself with the IdM. For every client application that is registered with the IdM, only one set of PEP credentials is available. Thus, if more than one resource needs to be accessed by the client app in a protected way, multiple PEP proxies are required that either share the same set of credentials or are dedicated to multiple (logical) applications that are registered with the IdM. On the other side, there is a very recent feature called "trusted apps" that allows one PEP to be used by different applications.

Wirecloud

One of the central aspects of our project was to provide a simple user interface via a web-based dashboard that should allow for:

- Administrating the IoT platform (creating, updating, deleting entities, adding/removing sensors, creating/deleting subscriptions).
- Visualizing the data using tables, gauges, maps, and all sorts of diagrams.

The final solution should be easily adaptable to different needs. For this purpose, the FIWARE ecosystem provides a component called Wirecloud (WireCloud Team, 2018). It is a web interface that allows for combining small building blocks called widgets or operators into dashboards in a very intuitive, easy-to-use way. Widgets are components that represent information graphically to the user, whereas operators provide functionality like reading data from other FIWARE services, transforming this data if necessary, and pushing it to other components like widgets. Widgets and operators are technically small JavaScript applications that come in zipped files with the extension ".wgt." These components can be shared—either for free or for a fee—via the FIWARE Store,[5] which is a very valuable resource providing lots of useful building blocks. It is also possible to share complete mashups (preconfigured networks of widgets and operators).

The most convincing feature is the simplicity in building mashups. As shown in Fig. 3, widgets and operators can be connected using a drag-and-drop editor. This is enabled by a configuration file that is part of every widget/operator and contains meta-information about input and output endpoints.

Besides this, it also exposes configuration properties (e.g., endpoint of the context broker) that can be defined/changed using a property editor. In this example, we

[5] https://store.lab.fiware.org/

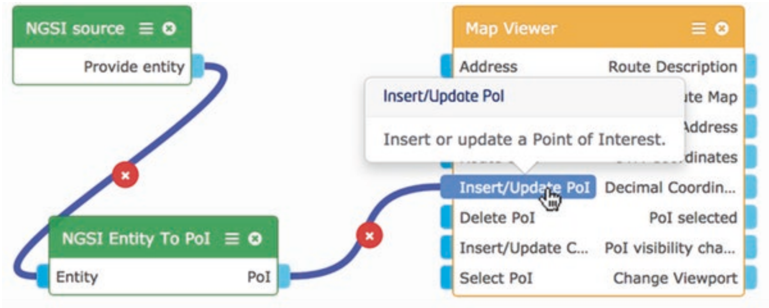

Fig. 3 Connecting component using the piping editor (Arranz, 2018)

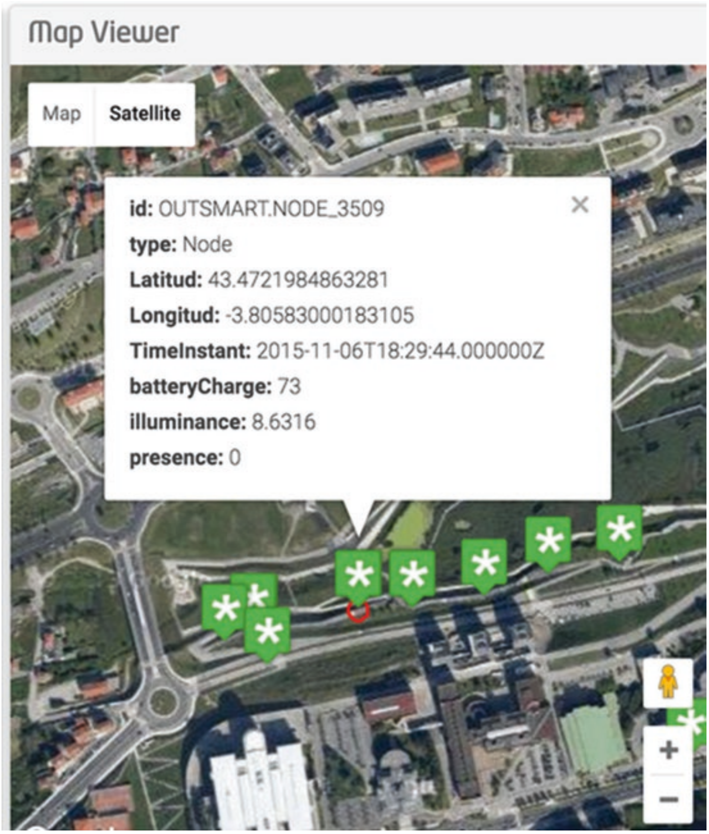

Fig. 4 Resulting Mashup (Arranz, 2018)

see an "NGSI source" operator that is configured to query the context broker for some entities. The "NGSI Entity to Poi" operator takes each entity and converts it into a POI object as it is needed by the "Map Viewer" widget. The result of this mashup can be seen in Fig. 4.

The Implementation

In the previous chapters, we have given a brief overview of the core components that we have used to implement our IoT platform. Figure 5 shows how these components have been wired together. For the sake of simplicity, the IdM and the PDP along with their interaction with the various PEP proxies have been omitted.

Security

Wirecloud is a web application that is implemented in Python using the Django framework.[6] Out of the box it comes with its own security mechanism, which, however, can easily be reconfigured to also support OAuth2 authentication using FIWARE's IdM. This allows for using FIWARE accounts to log into Wirecloud, and most operators that are designed to interact with other FIWARE components can be configured to add the OAuth token to their request. So, in our implementation, we let these components talk to PEP proxies while having blocked access to the actual FIWARE services. This allows for fine-grained end-to-end security.

Besides securing access to the Wirecloud dashboard and all other FIWARE services used by it, also the south-bound interface to the sensor network is protected. We deliberately used a separate PEP proxy that logically belongs to a different OAuth application. This allows for a clear separation between human users and sensors. Although the IdM allows for the creation of special sensor accounts, these accounts cannot be used in authorization rules. Thus, we are using normal user accounts also for sensors, allowing for a very restricted access to the IoT platform. Consequently, even if someone gets access to a sensor and its credentials, they can never be used to spoof any other identity, since the credentials used by a sensor only allow for delivering a predefined set of values to a specific endpoint that is exclusively dedicated to a single device.

Data Storage

As already mentioned before, Cygnus is an Apache Flume extension and provides the possibility to store historic data to one or more persistent storages. Figure 5 shows the two persistent storages used in our project, namely a MongoDB as well as a Hadoop Distributed File System (HDFS). The main purpose of the MongoDB is the storage of data used for visualization applications and dashboards. This means only recent data, relevant for the end users of the Wirecloud dashboard, will be provided by the MongoDB. HDFS, on the other hand, serves as basis for future data

[6] https://www.djangoproject.com/

processing and data analytics applications. Therefore, all data is additionally stored in HDFS.

In order to store historic data in two persistent storages simultaneously, Cygnus is configured to use one source, two channels, and two sinks. This configuration is shown by Fig. 6. The configured source is an http source and listens on a specified port for NGSI-like context data sent by Orion. Once the data is transformed into a Flume event, the event is moved into a Mongo channel on the one hand and a HDFS channel on the other hand. In general, an event consists of several headers and a payload, containing the actual historic data. As channels are passive components, the events stay in the channels until picked up by the sinks. Afterwards, the events are mapped into the required data structures and stored in the persistent storages.

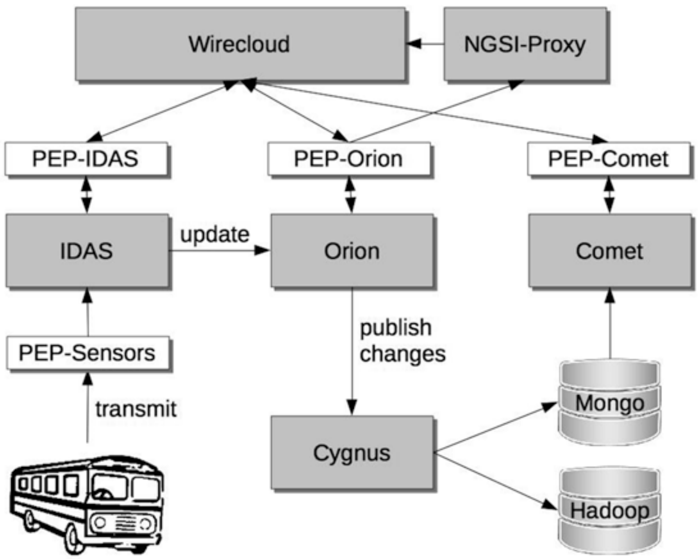

Fig. 5 The overall system architecture

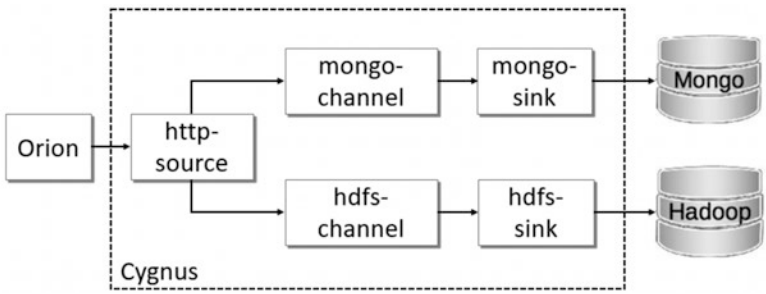

Fig. 6 Cygnus agent configuration

Cygnus provides a selection of predefined sinks for each persistent storage supported as well as the possibility to add new custom sinks. The provided predefined sinks can be configured by using a set of different parameters. Besides general configuration parameters like the host, port, user, and password of the storages, we configured parameters like the file format, batch size, and the batch time to live. Especially, when it comes to performance optimization of Cygnus, the batching parameters should be considered.

Retrieving Data

As described in section "The FIWARE Platform", FIWARE strictly separates the current state of the entire system and the historical data. The currents state is always represented by the data stored in the context broker, while historical data can be found in any of Cygnus' data sinks, and in the case of MongoDB, this data can be easily retrieved using Comet. Thus, to get this information, the context broker needs to get queried using the NGSI protocol. There already exist several off-the-shelf operators that can be retrieved from the FIWARE store. To always get the latest data, however, it is also possible to subscribe with the context broker. In this case, the context broker sends updates with every relevant change to the Wirecloud application. Since widgets and operators are written in JavaScript, they are running locally in the client's web browser. To be able to receive the broadcast messages, the NGSI-Proxy (see Fig. 5) is required. From the context broker's view, the NGSI-Proxy acts as the subscriber, and it forwards updates to the actual widget or operator via WebSockets.

Figure 7 shows an example of querying current and historic data. It first fetches a list of known devices (busses, trams, and traffic lights with sensors). When the user clicks on an entry in the list, the current values of temperature and humidity are displayed using gauges, while the last ten samples are visualized using a line chart. The number of points as well as the chart type can be easily changed, using the corresponding widget's settings dialog.

In Fig. 8, we see an alternative approach using a custom widget and operator that was created as part of the project. Instead of rendering entities as a table, they are presented as a form. This allows for selecting an entity (a distinct bus, tram, or traffic light), the sensor value of interest (depending on the capabilities of the sensors that report to the selected entity) and a time range.

Representing Spatial Data

In section "Wirecloud", we have already seen that rendering spatial data on a map is rather simple and straightforward using existing components. Basically, the same approach was used in our project, leading to the result shown in Fig. 9. All selected

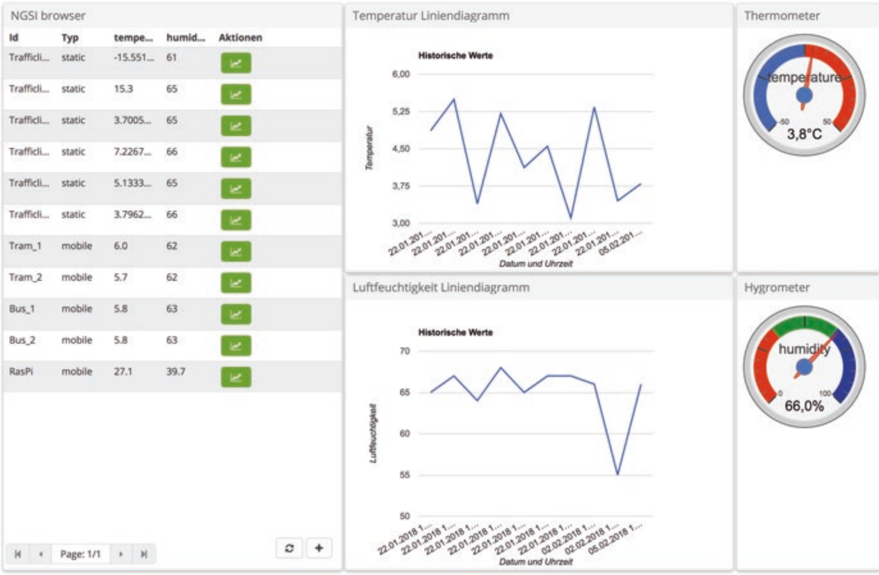

Fig. 7 Querying data based in a list of sensors

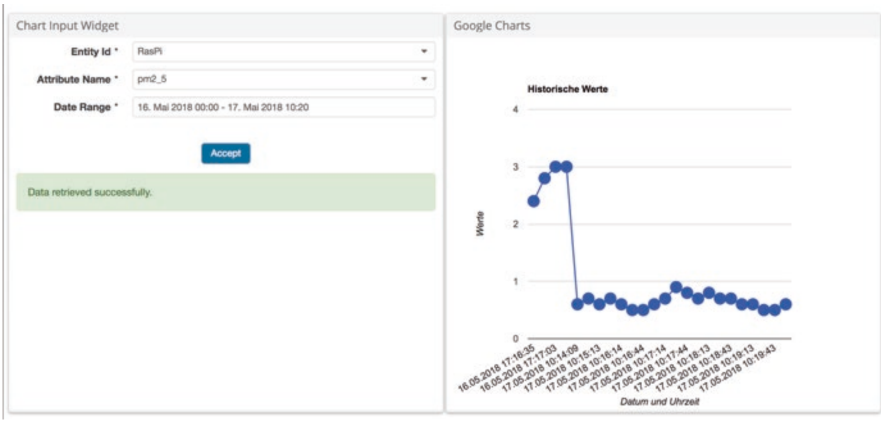

Fig. 8 Form-based query of historic data

sensors (mobile or stationary) are displayed using different icons representing the type of entity (e.g., bus, tram, light pole,...). Clicking on an icon will bring up all relevant information about the measuring point. Since the operators connected to this map make use of context broker subscriptions, every new sensor value is almost immediately displayed on the map. Consequently, all markers representing mobile sensors (busses and trams) are moving over the map in real time. Since there were

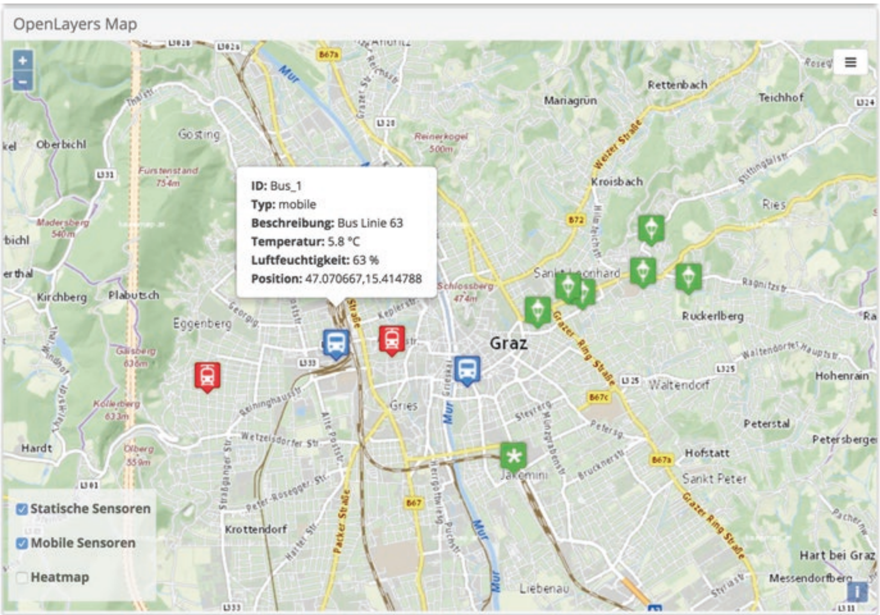

Fig. 9 Visualization of the current state

no such sensors available at the time of development, we have mocked them using a script sending periodic updates at locations along certain points defined in the script.

The only change compared to the standard components was the requirement to use a specific[7] open-source map instead of google maps.

While visualizing the current state of the system turned out to be straightforward, displaying "historic" data was a bit more demanding. Normally, time series are used to analyze trends over time. In case of mobile sensors (e.g., mounted on delivery trucks), they are often used to track routes. In this case, however, the idea of having mobile sensors was to cover a larger region of the city. Thus, it is not so much the location of the sensor that is of interest, but values of other sensors (e.g., air quality) that had been taken at this location. Analyzing a time window for mobile sensors therefore does not only simply reflect changes over time but also expands the area that was covered by these samples within this time frame.

So, to expand the spatial coverage of our "current state view," we have decided to also allow for including the last ten samples from any mobile sensor using a heat map. This factor can easily be changed, using the edit dialog of the underlying operator. The result can be seen in Fig. 10. Since the location of the mobile sensors is steadily updated, it appears like these sensors were trailing a tail of samples.

[7] https://www.basemap.at/index_en.html

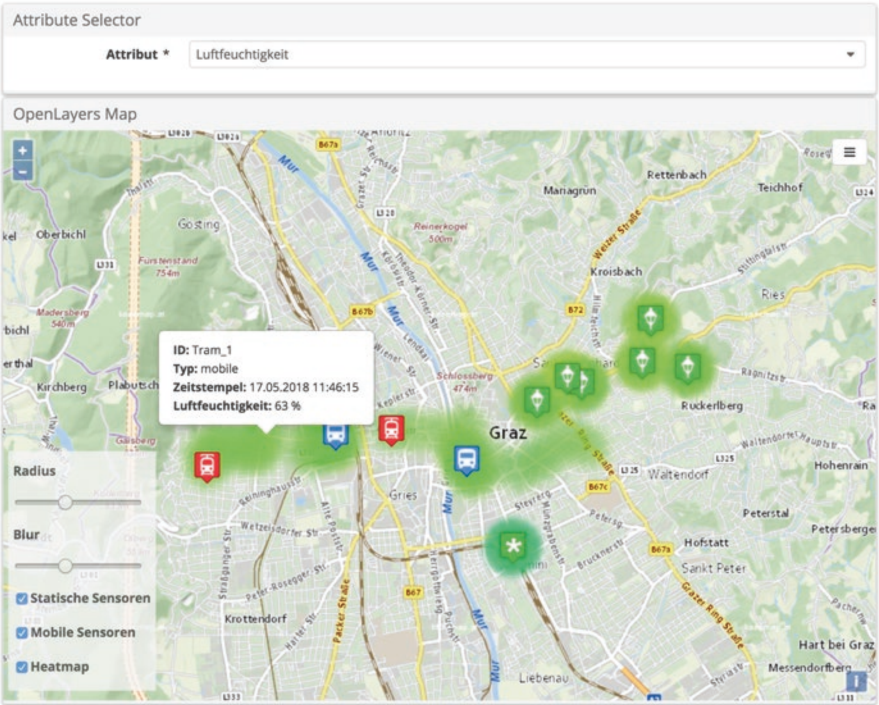

Fig. 10 Extending spatial coverage using a heatmap

Every data point is added as a marker, so they can be clicked to reveal all their details. While heatmaps usually only encode the density of their data points into a color schema, we had to refactor the existing heatmap in order to use the sensor value instead. Thus, an increased density of samples leads to decreased transparency while different sensor values lead to different colors. Since only one of the various sensor values can be used to be encoded by the heatmap, the user can select this value (e.g., temperature, humidity, PM2.5, PM10,…) using a simple drop-down field. Every sensor value is also mapped to its own color scheme, defining which values should be rendered as low (e.g., blueish), as normal (e.g., greenish), or high (e.g., reddish).

Apart from the question how best to use "historic" samples in order to expand the areal coverage in the "current state" view, a technical issue arose in querying historic data using Comet. In the case of the current state, entities stored in the context broker have been queried, which come with all sensor data (temperature, humidity,PM2.5,…). Once this data is processed by Cygnus (see section "Storing Time Series Data: Cygnus"), every value ends up in an individual document in the database. In the case of the MongoDB sink, there is one collection for every entity.

These collections contain documents for every sensor sample consisting of the following properties:

- recvTime: The time this sample was received by IDAS,
- attrName: Name of value (e.g., “temperature”),
- attrType: Data type of the value (e.g., “Float,” “geo:point,”…),
- attrValue: The actual value of that sample.

Thus, the only way to correlate those values that belong together is using the time stamp of every entry. Therefore, we needed a new Wirecloud operator that queries the last x entries for every sensor type and merges the individual results using their time stamp, so that we can combine a sensor value with the location it was taken at.

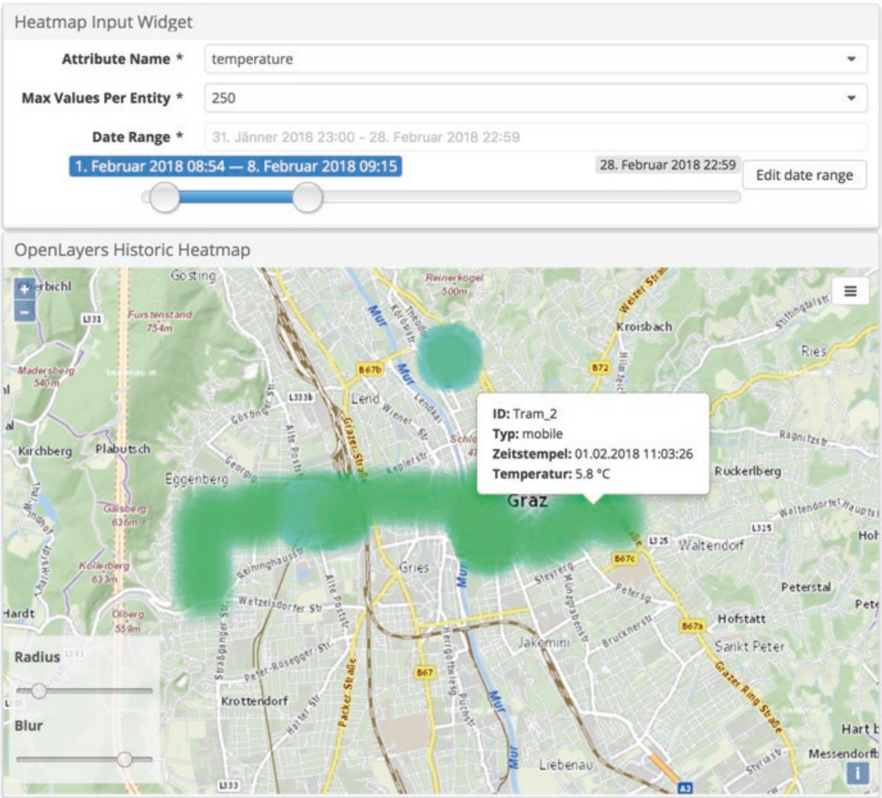

Fig. 11 Displaying historic data for a given time frame

Another important view in our dashboard is about representing "real historical" data on a map as it is shown in Fig. 11. Here the user can select the sensor type and a time frame of interest. As already mentioned, the modified heatmap uses the sensor value for color encoding, rather than the density of samples.

Providing an Administration Interface

Besides representing the data stored in the IoT platform, one goal of the smart city dashboard was to provide means for the administration of the entire system. It turned out, that the Wirecloud ecosystem already included most the required functionality. Based on these existing once, custom components have been created as needed.

Thus, we managed to create an admin interface that allows for maintaining all entities, services, and devices (see Fig. 12). This allows also for the onboarding of new sensors.

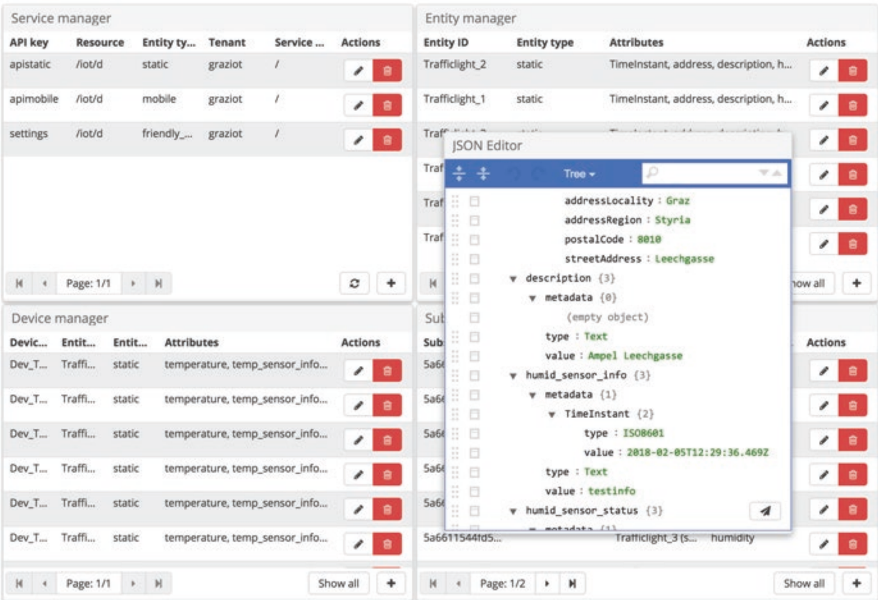

Fig. 12 The admin interface in the dashboard

Performance

Following the implementation of the prototype for a comprehensive sensor platform, the FIWARE components were migrated to a Kubernetes[8] cluster on a more potent server infrastructure. Kubernetes allows for automatic distribution of containerized applications over a number of nodes. This was the first step for realizing an actual IoT installation in a production environment and would make it possible to test the performance of the FIWARE platform in heavy load scenarios. The Kubernetes cluster itself was set up on four virtual machines with eight processor cores and 16 GB of RAM each. This design would make the sensor platform failure-resistant and would allow for a better distribution of the incoming traffic.

Testing Procedure

As the measurements of the deployed sensors would make up the majority of the traffic reaching the sensor platform, it was necessary to simulate a large number of sensors to get viable results for the performance tests. For this purpose, the Java application Apache JMeter (The Apache Software Foundation, 2019) was chosen because it is open source, very mature, and supports all sorts of testing scenarios. It enables the user to create complex test plans and allows for a very detailed analysis of the gathered results. In this specific test scenario, the individual sensors were simulated by sending simple http requests with random sensor values to the external PEP proxy of the IDAS component. The desired quantity of sensors could be defined by setting the count of parallel threads for the JMeter test plan to the respective number. To make the test procedure more realistic, a delay of 5 s was introduced after every batch of http requests from JMeter. This should replicate the timeout between the individual measurements as it would occur with real sensor devices. In addition to the imitated sensor values, the test plan also included a timed http request for acquiring a valid OAuth2 token from the Keyrock instance to allow for a successful authentication with the IDAS PEP proxy.

To create the necessary entities for all the simulated sensors in the FIWARE platform, we wrote a Python script which could generate the JSON structure for a large number of test sensors. The resulting JSON file could then be uploaded in a specific Wirecloud widget, which created all the required objects in the database.

As the test results from the JMeter application only contained information regarding the successfully delivered http requests, additional monitoring of the involved infrastructure was needed. For this reason, we recorded the log outputs of all the active FIWARE components to individual files and saved the output of the resource monitoring software "top" (Kerrisk, 2018) to get a better overview of the internal condition of the whole sensor platform during the test runs.

[8] https://kubernetes.io/

The actual test runs were performed from another virtual machine in the same network as the Kubernetes cluster to minimize the risk of getting distorted results from potential network issues.

Performance Evaluation

The main approach for testing the performance of the IoT installation involved running several iterations of the JMeter test plan with different quantities of simulated sensors. The initial idea was to start with smaller numbers (around 100 sensors) and gradually increase the sensor count to 100,000.

After the first few passes, it became clear that the platform in its current configuration would only be able to handle a fraction of this load. The summary of the first JMeter test runs showed less than 100 completed requests per second, averaged over a runtime of 5 min. Considering the 5-s delay after each batch of requests, this would amount to a maximum number of under 500 sensors running in parallel. Subsequent test runs with higher numbers of threads and runtimes up to 1 h showed no improvement in this regard.

After the first testing phase, we evaluated the current configuration of the IoT installation and came up with three potential optimizations: adapting the configuration of the Cygnus component, scaling the number of instances of strained FIWARE components, and replacing the single instance MongoDB with a clustered variant.

The test results did not show a significant correlation between the performance of Cygnus and the number of completed requests per second, but examining the logs revealed a different problem. The database transactions triggered by incoming sensor measurements were lagging quite considerably, which resulted in a delay of almost 30 min over a test runtime of 1 h. After evaluating the configuration of the Cygnus component, we found that increasing the batch size for transactions could help with this problem (FIWARE Cygnus Team, 2016). After increasing the batch size from 100 to 10,000, we could indeed detect an improvement, which showed as a drastically reduced delay of less than 1 min.

To reduce the stress of high network loads on individual FIWARE components, we decided to use the native scaling mechanics of the Kubernetes cluster. To find out which component would benefit the most from having multiple instances, we conducted tests with the PEP proxy, IDAS, Orion, and Cygnus components scaled up to four instances each. While scaling the PEP proxy and IDAS components did not show any apparent change, doing the same with Orion and Cygnus showed a quite substantial improvement to 180 completed requests per second from the initial 100 using a thread count of 1000.

As the performance of the platform was still not optimal, considering the available hardware resources of the infrastructure, we decided to analyze the situation of the underlying MongoDB instance. To optimize the performance of the database, it was necessary to deploy a “Sharded Cluster”(MongoDB, 2018), which allowed to spread the database transactions over several nodes and furthermore provided a failsafe environment. As test scenario we used the same procedure as with the scaled FIWARE components. Unfortunately, performing these test runs with the MongoDB cluster in place yielded worse test results than those with the single MongoDB instance. While simulating 1000 sensor devices, the average number of completed http requests went down from 180 to around 145. Increasing the thread count to 1500 even led to dropped connections during the test runs and utilizing 2000 threads resulted in a crash of one of the Kubernetes nodes. Monitoring the resource usage of the infrastructure during these tests showed that the MongoDB cluster used up the majority of available RAM even while being idle. Therefore, we speculated that putting the database cluster under stress resulted in an exhaustion of system resources which led to one of the virtual machines crashing. From these results, we concluded that while the former optimization attempts could indeed improve the performance of the platform, the implementation of the MongoDB cluster, combined with the other necessary components of the FIWARE infrastructure, would require a considerable increase in available hardware resources.

Conclusions

The idea of the whole project was to figure out, whether it is possible to create a comprehensive, production-class IoT platform using the FIWARE stack with minimal effort. It turned out that all the core components we had to use worked out-of-the-box without any errors. The Wirecloud platform used for implementing the dashboard is based on a well-designed architecture. There is a clear separation between UI-components (widgets) and components to provide and to manipulate data (operators), which greatly improves reusability. All these components can be combined to powerful mashups without a single line of programming using the piping editor. Besides managing connections visually, every single component can be configured using a form-based dialog. The FIWARE store allows for sharing these components and provides hundreds of widgets, operators, or preconfigured mashups. Even if the required component cannot be found there, new ones are easily created using simple JavaScript. Consequently, the amount of necessary programming was extremely low especially compared to the achieved result.

Another surprising outcome was the resource consumption and the performance of the whole system. We are hosting our platform in the FIWARE Lab Cloud. The application consists of 15 docker containers that are running on a single virtual machine with two cores and 4GB RAM. Although the data model currently consists of only 11 entities representing the setting of the planned implementation (2 busses, 3 trams, 6 static sensors), there is a relatively high number of services running on a single machine. Nevertheless, no notable latency in working with the system occurs. In the additional performance tests, which were carried out during the follow-up project, we initially ran into severe performance problems. One of the reasons was a misconfiguration of Cygnus, which is used to persistently store sensor data to various data sinks (MongoDB and Hadoop in our case). Changing the configuration improved the situation. Another in-depth analysis combined with changes of the entire setup revealed that another bottleneck is the security layer with the communication between the PEP and the IdM. Testing without the security layer in place further improved the results but with several 100 sensors we could still not meet our high-performance expectations. On the other side, as our test with a differently configured database showed, all resources (FIWARE components, MongoDB, and Hadoop) are all using the same set of resources, leading to a resource competition. Thus, we cannot exclusively blame the FIWARE components for the relatively poor results.

Consequently, our lessons learned were that as far as the setup of a smart city platform is concerned, FIWARE is a good choice, while there seem to exist some performance issues that we could not clearly attribute to a specific component.

Besides this, current activity on the various GitHub repositories indicates that there is a lively community behind the platform. Thus, we would expect that with a broader uptake of the framework all sorts of problems will be identified and eventually fixed.

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Toward an Open IoT Implementation for Urban Environments: The Architecture of the *DBL SmartCity* Platform

Siniša Kolarić and Dennis Shelden

Abstract Smart cities collect and utilize various types of geo-referenced data in order to enhance the performance and quality of urban services, such as governance, transportation, energy use, and air quality monitoring. Information and communication technologies (ICT), including Internet of Things (IoT) systems and networks, constitute an essential component of smart city initiatives. In this chapter, we describe the architectural considerations behind our recently introduced, open *DBL SmartCity* platform for managing geo-referenced IoT data typically generated in urban environments. One of the principal requirements selected for the platform involved the utilization of open data standards, open data transfer protocols, and open data formats in order to facilitate interoperability and data exchange. Another requirement concerned platform scalability, which was achieved through the adoption of open-sourced "big data" and streaming computing frameworks, libraries, and technologies. The platform also fulfills the *modularity* requirement as it is able to exchange its parts and modules with alternative, functionally equivalent technologies.

Keywords DBL Smart City Platform · Internet of Things implementation · Urban environments · Urban services · Open Internet of Things

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_16

Introduction

Currently, cities and societies face a number of challenges, such as excessive energy consumption, governance issues, waste management, noise levels, building structure monitoring requirements, and traffic congestion (Scholl & Scholl, 2014; Zanella, Bui, Castellani, Vangelista, & Zorzi, 2014). To meet them, various *smart city* initiatives have been proposed by both industry and academia (Estevez, Lopes, & Janowski, 2016). For example, Hall et al. (2000) offer the following definition of smart cities:

> The vision of "Smart Cities" is the urban center of the future, made safe, secure environmentally green, and efficient because all structures-whether for power, water, transportation, etc. are designed, constructed, and maintained making use of advanced, integrated materials, sensors, electronics, and networks which are interfaced with computerized systems comprised of databases, tracking, and decision-making algorithms.

Giffinger and Gudrun (Giffinger et al., 2007; Giffinger & Gudrun, 2010) detail how smart cities rank highly for seven dimensions, namely economy, human capital, governance, mobility, information and communication technologies (ICT), natural environment, and quality of life. Nam and Pardo (2011) suggest that smart cities excel in the three dimensions of *technology* (sensing, networking, data storage, and data processing technologies), *people* (education and learning), and *institutions* (governance). Chourabi et al. (2012) identify eight factors underlying smart city initiatives, namely management and organization, technology, governance, policy context, people, economy, built infrastructure, and the natural environment. An excellent introduction and a systematic literature review on the topic of smart cities has been authored by Cocchia (2014).

ICT as well as Internet of Things (IoT) systems, networks, and platforms in particular are considered as distinguishing characteristics and essential components of all smart city initiatives (Giffinger et al., 2007; Giffinger & Gudrun, 2010; Nam & Pardo, 2011). The concept of IoT was initially proposed as part of an early supply chain management application (Ashton, 2009). It refers to a novel technological paradigm where billions of objects connected through the Internet have the ability to automatically sense, actuate, communicate, and process information. Zanella et al. (2014) and Rathore, Ahmad, Paul, and Rho (2016) argue that IoT represents one of the cornerstones of any smart city initiative. Many potential applications of IoT have been suggested in the literature, including smart cities (Rathore et al., 2016) and smart buildings (Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012). Survey papers (Khan, Khan, Zaheer, & Khan, 2012; Miorandi et al., 2012) enumerate many more potential applications of IoT, such as infrastructure monitoring, energy management, and vehicle fleet management.

The Need for Open, Interoperable Smart City IoT

IoT is currently characterized by a rapid growth in the number of new products (such as devices, services, applications, and platforms), all of which utilize heterogeneous data protocols and standards in order to communicate with each other. Furthermore, individual companies are incentivized to constantly improve on the functionality of their own IoT products while paying little regard to the ability to communicate with other, similar IoT products developed by competing companies (Fältström, 2016).

This commercial impetus toward divergent, in-house IoT development, as well as the lack of open IoT standards may lead to the creation of vertical "silos" or systems, which cannot be easily extended with third-party components, thus resulting in the vendor "lock-in" phenomenon. Vendor lock-in can negatively affect public funding of smart city initiatives, since switching to another vendor might be prohibitively expensive (Ahlgren, Hidell, & Ngai, 2016).

Other ensuing issues include the lack of interoperability[1] among IoT products (Bröring et al., 2017), as well as slower growth of the market associated with IoT systems, devices, and services (Fältström, 2016). In yet another potential downside, relying on a single provider might lead to a suspension of the IoT system's operation due to IoT platform outages (Satzger, Hummer, Inzinger, Leitner, & Dustdar, 2013).

An effective IoT platform for the smart city approach must also provide robust support for handling data that are typically used to describe built environments, such as spatial, 3D, and geo-referenced data. This includes data commonly used in the architecture, engineering, and construction (AEC) industry, as well as various 2D/3D geometric data managed by Computer-Aided Design (CAD) and Building Information Modeling (BIM) systems (Eastman, Teicholz, Sacks, & Liston, 2011). As in the case of IoT systems and platforms, interoperability is considered to be a long-standing problem in AEC on account of the many heterogeneous systems being used in the industry (Grilo & Jardim-Gonçalves, 2010).

Due to these issues, there is a need for IoT implementation that (1) is non-proprietary, (2) provides strong support for integrating spatial, 2D/3D, BIM, and geo-referenced data, (3) facilitates interoperability by utilizing open data transmission and encoding standards, and (4) allows open access to data by providing a set of well-designed Application Programming Interfaces (APIs). To address this need, we have initiated an open-source project to support the smart city approach. Named *DBL SmartCity*, this initiative aims to provide such an open IoT platform.

In this chapter, we describe the architectural considerations behind the conceptual design of the platform. We first describe the high-level requirements that were selected for the platform in section "The *DBL SmartCity* Platform". We then delineate the types of data and storage used for the platform in section "Data Typology

[1] Interoperability can be defined as "a measure of the degree to which diverse systems, organizations, and individuals are able to work together to achieve a common goal" (Ide & Pustejovsky, 2010).

and Storage". We detail data processing issues as well as ways to extract, analyze, transform, retrieve, or classify data in section "Data Processing". We briefly review the bundled browser-based application prototype, which is based on an open, streaming virtual globe library (Cesium.com, 2020), in section "Interacting with Data", and we describe how the platform lends itself naturally to federating multiple nodes in section "Support for Federated Nodes". We discuss the presented material, issues, and considerations in section "Discussion". Finally, we summarize the main ideas of this chapter as well as future work in section "Conclusions and Future Work".

The *DBL SmartCity* Platform

We recently introduced *DBL SmartCity*, an open-source IoT platform geared toward managing 3D and spatiotemporal data characteristic for built and urban environments (Kolarić, 2020; Kolarić & Shelden, 2019). In response to the issues listed in section "Introduction", we selected the following high-level design requirements to guide us during the conceptualization of the platform:

- *Openness*. Interoperability and data exchange in IoT are difficult due to the existence of proprietary data formats and protocols (Ahlgren et al., 2016). To avoid these issues, the platform should be based on open data standards, open data serialization formats, open data exchange protocols, and open-source software licenses. It should also offer a set of APIs in order to enable open access to data.
- *Scalability*. The platform should also allow for effortless scaling of store and compute workloads (Lehrig, Eikerling, & Becker, 2015). In fact, "big data" and "big analytics" are considered to be essential capabilities of effective IoT systems (Mitchell, Villa, Stewart-Weeks, & Lange, 2015).
- *Support for AEC data*. The platform should provide an effective means to interact with large heterogeneous sets of 2D and 3D data typical for urban environments, such as geometric models of environmental objects (e.g., buildings, roads, bridges, and vegetation), as well as 2D annotation data embedded within 3D scenes.
- *Modularity*. In addition to the customizability provided by the nature of open source, the platform's design and architecture should allow for modularity. To begin with, each subsystem within the platform should be interchangeable with another subsystem with equivalent functionality. Next, the platform should allow for easy addition of plugins, extensions, and "apps" through a framework that allows users to develop, install, and use custom interactive modules produced by third-party developers.

The Overall Platform Architecture

Currently, no single reference IoT system architecture exists that is suitable across all vertical and horizontal applications (Krčo, Pokrić, & Carrez, 2014). For instance, Khan et al. (2012) present a generic IoT architecture that consists of five layers (perceptual, network, middleware, application, and business). Li, Xu, and Zhao (2015) propose a generic service-oriented architecture (SOA), which consists of four layers (sensing, network, service, and interface). Al-Fuqaha, Guizani, Mohammadi, Aledhari, & Ayyash (2015) describe four different ways to conceptualize IoT system architectures: (a) three-layer architecture (perception, network, and application), (b) middle-ware-based architecture, (c) SOA, and (d) five-layer architecture. Krylovskiy, Jahn, & Patti (2015) present a microservice architecture used to design a smart city IoT platform and describe its advantages when compared to more generic SOA approaches. Rathore et al. (2016) report an IoT approach for urban planning and design of smart cities based on big data analytics using a four-layer model (data generation and collection, communication, data management and processing, and data interpretation). In the industrial sector, influential reference IoT platform architectures have been implemented and marketed by IBM, Inc. (2020), Cisco, Inc. (2020), Microsoft, Inc. (2020a), Amazon, Inc. (2020), and Google, Inc. (2020a).

Based on prior approaches to IoT architectures as well as our high-level requirements for the *DBL SmartCity* platform, for the initial interaction we propose the multitier architecture shown in Fig. 1. The architecture consists of several layers through which data are collected, processed, and finally presented to the users for interaction. In the following section, we briefly describe each tier of this architecture.

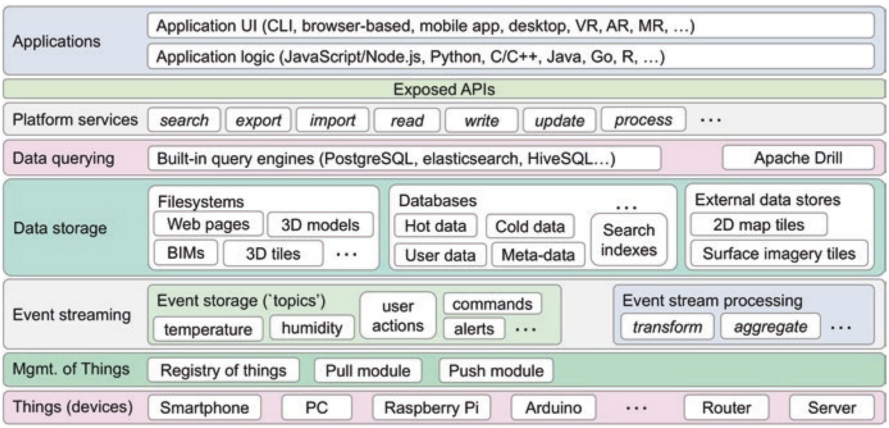


Fig. 1 Multitier architecture of the *DBL SmartCity* platform

"Things" (IoT Devices) Tier

This tier includes various "things" in the Internet of Things, which in turn control a variety of sources of data (such as sensors), or sinks of data (for example, actuators), or source/sink combinations (such as, for example, a memory location describing the intensity of a light source). In addition to sensors, other typical sources of IoT data may include system logs, clickstreams, telemetry data, data feeds (including social data feeds), and general software. Other types of common sinks of IoT data may include servo mechanisms and general software.

We note that many end IoT devices are underpowered and may not be able to run a full TCP/IP networking stack on wired (Ethernet, serial) and wireless (Wi-Fi) connections. Additional suitable networking protocols for low-powered IoT devices include Zigbee, Message Queuing Telemetry Transport (MQTT), CoAP, HTTP, and 6LoWPAN.

While prototyping the first iteration of the *DBL SmartCity* platform within our test bed (the main Georgia Tech campus located in Atlanta, US), we have collected data from sensors generating temperature, humidity levels, light intensity, sound frequency, and loudness level data. In addition, we collected energy readings from Johnson Controls managed by the Facilities Management department at Georgia Tech.

Management of "Things" Tier

This tier contains modules for discovering, registering, and de-registering IoT devices used with the platform. In addition, this tier supports polling of published sensor data feeds (such as public transit feeds and social media feeds), as well as "pushing" data back to registered IoT devices, for instance by sending a command to an actuator.

While prototyping the platform, we used a public data feed by MARTA (Metropolitan Atlanta Rapid Transit Authority), as well as a data feed generated by a sensor cluster located at the RICAL lab at Georgia Tech.

Event Streaming Tier

This tier asynchronously collects and processes messages emitted and received by IoT devices. Collected data is then forwarded to two main processing pipelines: the real-time pipeline and the long-term data pipeline. In addition, data can also be forwarded to (or received from) other *DBL SmartCity* nodes if necessary or desired. In other words, event streaming tier can be used to interlink multiple *DBL SmartCity* nodes, thus achieving federation and syndication (see section "Support for Federated Nodes").

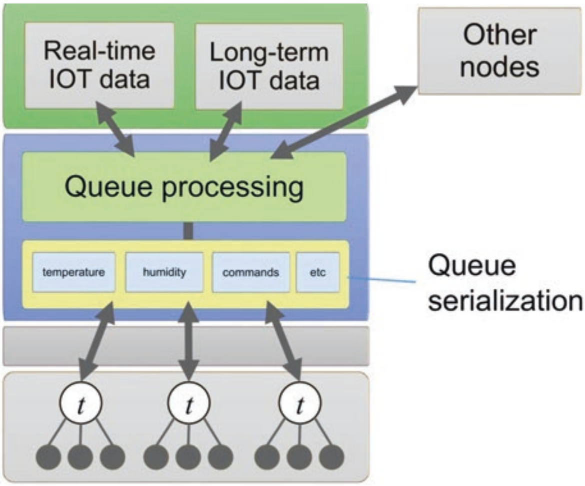


Fig. 2 Event streaming tier

Figure 2 depicts the entities within this tier. Some of the scalable, high-performance, fault-tolerant, open-sourced messaging system that are well suited for IoT messaging and microservices architectures include the low-footprint NATS message broker (Synadia Communications, Inc., 2020), as well as the Apache Kafka message broker (Apache Foundation, 2020a).

In addition to storing and forwarding event messages, this tier is also concerned with the real-time *processing* of event message streams. The main goal of said processing is the analysis and transformation of large volumes of immutable event data, as well as providing useful insights into the event data prior to saving it into short- and long-term storage in the next tier. Effective choices for real-time queue processing include Apache Spark Streaming (Apache Foundation, 2020b), an extension to the Apache Spark compute engine, which provides for scalable, high-throughput, fault-tolerant stream processing of live data streams. Another viable option, especially for smaller deployments, is Kafka Streams (Apache Foundation, 2020c).

Data Storage Tier

This tier encompasses data stores for serializing streaming data ingested through the event streaming tier, such as filesystems and databases that store both the real-time and historical time-series data. In addition, external data sources (providers) serve 2D data such as maps, satellite imagery, and terrain datasets, which are usually partitioned into hierarchical tiles. The data model is therefore a hybrid one, recombining four principal kinds of data: streaming geometry data, database (alphanumeric) data, various kinds of 2D data (such as surface imagery), and other types of data (such as annotation data). We detail the modules contained in this tier in section "Data Typology and Storage".

Data Querying Tier

This layer utilizes both built-in data querying engines (such as those provided by databases natively) and more specialized, scalable search engines. The former engine types are suitable for low to moderate volumes of data and latter for large volumes of data. Query engines can connect to different types of data sources, including sources of structured, partially structured, and even unstructured data such as documents, images, and photos.

For smaller deployments of the platform, data querying functionality is provided through built-in query engines. For larger installations, options include Apache Drill (Apache Foundation, 2020d), Apache Impala (Apache Foundation, 2020e), Spark SQL (Apache Foundation, 2020f), and Presto engines (Presto Software Foundation, 2020). The advantages of the Apache Drill engine include its full SQL support, the ability to simultaneously connect across many types of data stores (SQL, NoSQL, semi- and unstructured data, thus providing a single connection point), and low-latency queries over massive amounts of data.

Platform Services Tier

This tier encompasses computational services that connect to data stores through the data querying layer, retrieve data, perform processing on data, and potentially write processed data back into data stores. Platform services can be written in a host of programming languages (JavaScript, Python, Scala, Java, Go, shell scripting), and then executed within environments and frameworks such as Node.js, MapReduce, and Apache Spark. In addition, selected implemented services can be exposed to third-party developers through their own REST API in the upper tier. For instance, one such service takes a BIM model as input and converts it through several steps to the Cesium 3D tiles streaming format (see section "Data Pipeline B: From IFC to Streaming 3D Tiles").

Public API Tier

As per Ahlgren et al. (2016), in order to achieve open systems, "systems need to be designed with openness in mind at all levels." This particularly applies to the public API tier, since it directly enables open access to data.

A selection of services implemented at the preceding level are exposed through their own public REST application programming interface. The acronym REST stands for *Representational State Transfer*, an approach to building decoupled networked systems (Fielding, 2000), which is based on the following six principles: client-server, uniform interface, stateless, cacheable, layered system, and code on demand. In REST, any "resource" such as a 3D model/feature, web page, image, and video is identified by its URI. RESTful applications implement four main operators acting on a resource: Create, Retrieve, Update, and Delete (also called "CRUD" operations). For example, a platform API endpoint allows the user to both Retrieve (download) and Update/Create (respectively, upload) 3D models and datasets, thus implementing all four CRUD operations.

Applications Tier

Using the exposed APIs as well as the bundled web client application, third-party developers can build custom applications, such as real-time monitoring and analytics on geo-referenced and 3D-object-linked sensor data and visualization of energy simulation data.

The final Cesium scene, as displayed to the user in the bundled *DBL SmartCity* web client, is composed by visualizing data drawn from several sources. First, a 2D (surface) tileset provided by a surface imagery vendor such as MapBox, Esri, and Microsoft Bing and superposed on the Earth's surface, modeled by the World Geodetic System (WGS84). The global 3D tileset is styled dynamically (at runtime), followed by any secondary data such as data displayed as annotation within the 3D scene or data displayed in GUI dialogs.

Data Typology and Storage

In this section, we detail the typology of data managed within the platform, as well as storage types. Once the streaming data has been ingested through the event streaming tier, it is forwarded to, and saved into, the data tier. The requirements of building an IoT platform give rise to several different types and forms of data, both at the physical and logical level. For readers' convenience, we repeat the relevant part of Fig. 1 (i.e., only the storage tier) in Fig. 3.

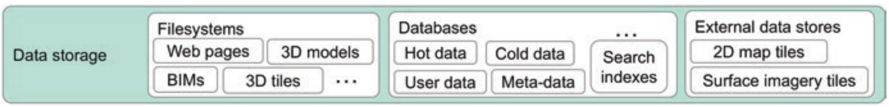


Fig. 3 Storage tier in the *DBL SmartCity* platform

Filesystems. Filesystems are used for storing files such as web pages, client-side scripts, style sheets, BIM data, and 3D model data. Converters are used in order to convert 3D and BIM IFC data into the 3D tiles format (.b3dm), as well as intermediary formats such as the Wavefront 3D model format (.obj) and GL transmission format (.glTF). Additional converters may transform files using proprietary BIM (Autodesk Revit) format into 3D tiles format as well.

Databases. Various databases (SQL and NoSQL) store both the real-time (RT) and historical time-series data collected from and sent to IoT devices registered with the platform. As one significant classification, databases serialize and save *hot* (real-time, current) data as well as *cold* (long-term, consolidated, historic) data.

External data stores. The platform utilizes external data sources (providers) such as MapBox, Inc. (2000), foremostly for 2D data such as maps, satellite imagery, and terrain datasets. Associated datasets are very large and are often partitioned into hierarchical tiles. Using the virtual globe library by Cesium.com (2020), surface imagery from said third-party providers is included and rendered directly in the bundled web client application.

WGS84: The Default Georeferential System

Since the platform is conceptualized with emphasis on geo-referenced data typically generated within urban environments, we use the World Geodetic System (WGS84) as our default referential system. WGS84 is one of the most used and influential models of Earth that is based on the idealized ellipsoid shape and, among other applications, used for GPS calculations and applications, as well as in the Cesium virtual globe library (Analytical Graphics, Inc., 2020; Cesium.com, 2020). WGS84 is to be contrasted to the "geoid" sea level model based on an equipotential surface determined by the Earth's gravitational field (Microsoft, Inc., 2020b).

In addition to the elevation coordinate as defined within the WGS84 referential system, the platform uses the values of *longitude* and *latitude* in order to unambiguously define any arbitrary location on the Earth. Latitude defines the angular distance of a location in the south-north direction, ranges from −90.0° (South Pole) to 0.0° (equator) to +90.0° (North Pole). Longitude on the other hand defines the angular distance of a location in the west-east direction, ranging from −180.0° (the opposite of the Greenwich meridian, when proceeding in the westward fashion) to 0.0° (Greenwich meridian) to +180.0° (returning back to the opposite of the Greenwich meridian, in the eastward fashion). The triple (longitude, latitude, elevation) then fully defines a point on the Earth.

Cesium 3D Tiles for Streaming Geometry Data

Among multiple standards for decomposing Earth's surface into rectangular *tiles*, arguably the most widely adopted one follows the |*zoom/x/y*| (or so-called "slippy") scheme. It has been used by organizations such as OpenStreetMap, Google Maps, MapBox, and MapQuest (Fig. 4). For slippy maps tiling scheme, the tiles' widths remain equal (in radians or degrees) for any latitude. However, tiles' heights decrease (again, in radians or degrees) as one nears poles.

Similar to 2D tiles, the "3D tiles" format by Cesium (Analytical Graphics, Inc., 2020) represents a way to subdivide 2D and 3D geometric data describing objects situated on the Earth's surface (such as buildings, infrastructure, and vegetations) into nested, hierarchical *tiles*. The 3D tiles format supports streaming of massive heterogeneous 3D and geospatial data. As per the specification, *features* are packed into *3D tiles*. 3D tiles are packed, in turn, into hierarchical structures called *3D tilesets*, which follow the same precepts at those for 2D mapping tiles.

Features

A feature is the smallest addressable component of any 3D tile. For example, a feature may represent a 3D model of a building, a 3D instance of a tree model, a point in a 3D point cloud, or a vector (polyline, rectangle, sphere) embedded in 3D space. For each feature, its attributes (such as latitude, longitude, height) must be encoded as a data structure called *batch table* and that is embedded into any 3D tile.

The partial JSON snippet shown in Fig. 5 illustrates which attributes (id, name, longitude, latitude, and zip code) will be associated with features (in this case, buildings) in the resulting 3D tile.

Fig. 4 Map tiling based on the zoom/x/y ("slippy") scheme, with zoom levels from 1 to 14. Image created by S. Kolarić using map tiles released by Stamen Design LLC (2019) under CC BY 3.0 license

```
...
{
  "id" : "47",
  "name" : "Architecture Building (West)",
  "longitude": "-84.396109",
  "latitude": "33.776099",
  "zip" : "30318",
  ... (other attributes)
},
{
  "id" : "48",
  "name" : "John and Joyce Caddell Building",
  "longitude": "-84.397024",
  "latitude": "33.777548",
  "zip" : "30318",
  ... (other attributes)
},
...
```

Fig. 5 An excerpt from a batch table used for building features

```
{
  "boundingVolume": {
    "region": [
      -1.3197351054587685, // (in radians)
      0.698829173006603,
      -1.3196243108779218,
      0.6989177498576029,
      0.0, // (in meters)
      271.4
    ]
  }, ...
}
```

Fig. 6 Bounding volume for a 3D tile

3D Tiles

A number of features may be packed into a Cesium 3D tile which may be regarded as a container that encloses a region of 3D space in the WGS84 terrestrial reference system. It is defined by the six parameters of west, south, east, north, minimum height, and maximum height. A 3D tile can contain any of the following: a batch of 3D models (*.b3dm), a set of 3D instances (*.i3dm), 3D point cloud (*.pnts), and 3D vector data (*.vctr). Figure 6 illustrates how a 3D tile and its bounding volume may be defined using JSON.

3D Tileset

Finally, a 3D "tileset" is a set of multiple tiles that are organized into a hierarchical, spatially coherent data structure, either an octree or an k-d tree, whose bounding volume encloses all the constituent tiles' bounding volumes. A tileset is encoded as a *tileset.json* file that follows the overall structure shown in Fig. 7.

```
{
  "root": {
    "refine": "add",
    "content": {
      "url": "0/0/0.b3dm"
    },
    "children": [{
      "content": {
        "url": "1/0/0.b3dm",
      },
      "children": [...]
      }, {
        "content": {
          "url": "1/1/0.b3dm",
        },
        "children": [...]
      }, {
        "content": {
          "url": "1/1/1.b3dm",
        },
        "children": [...]
      }]}
}
```

Fig. 7 An excerpt from a *tileset.json* file defining a 3D tileset

Databases and Data Schemas

In addition to the streaming geometric data encoded within 3D tiles, various database schemas store other pertinent geo-referenced data, such as *IoT data* (i.e., data about geo-referenced things, sensors, actuators, tasks, observed properties, observations, and data streams of observations), *geocoded locations* (addresses, places, and points of interest), *authentication data* (information about users, things, and their permissions), *real-time data*, *long-term data* (i.e., consolidated data), *data for analytics* (aggregated data suitable for online analysis), and data specific to any custom-developed apps.

For instance, the database schema containing IoT data within the *DBL SmartCity* platform was heavily influenced by the Open Geospatial Consortium's (OGC) own IoT schema (Open Geospatial Consortium (OGC), 2020a), which has been maintained by OGC within its Sensor Web Enablement (SWE) stream, and later drafted as the ISO 19156:2011 standard by the International Organization for Standardization (2011).

Real-Time (Hot) vs. Historic (Cold) Data

Within the platform we distinguish, in main, between real-time data and long-term (consolidated, historic) data.

Hot (real-time) IoT data pipeline. Hot data is concerned with real-time (high-velocity data, either low-volume or high-volume) applications such as dashboards, real-time or near real-time monitoring, real-time analytics, event detection, and event response management (both manual and automatic). In *DBL SmartCity*, we implemented the ingestion of time-series data using TimescaleDB (Timescale, Inc., 2020), a time-series database extension for PostgreSQL (OpenTSDB.net 2020). For large-scale installations, one may deploy an Apache Cassandra (Apache Software Foundation, 2020a) cluster.

Other viable alternatives for time-series databases (TSDBs) include InfluxDB (InfluxData, Inc., 2020), KDB+ (Kx Systems, Inc., 2020), RRDtool (Oetiker, 2020), and OpenTSDB (OpenTSDB.net, 2020). For real-time data visualization such as dashboards, monitoring, real-time analytics, one may use Grafana (Grafana Labs, 2020) and Apache Superset.

Historic IoT data pipeline. This layer is concerned with storing, processing, and accessing historical data, such as past sensor data (time series) and interaction audits. It also contains various types of derived data, such as aggregated data and statistically derived data, in order to support applications such as decision-making support, machine learning, and analytics.

For smaller installations, one may save historic data into a PostgreSQL (The PostgreSQL Global Development Group, 2020) instance. For larger installations, one may use the Apache Hadoop framework/ecosystem (Apache Software Foundation, 2020c) which utilizes networks of inexpensive, commodity computers in order to implement "big data" distributed data storage capabilities. Components of this framework include the Hadoop Distributed File System (HDFS) for storing very large files as well as various data stores built on top of HDFS, such as Cassandra (Apache Software Foundation, 2020a), Hive (Apache Software Foundation, 2020d), and HBase (Apache Software Foundation, 2020e). In order to process aggregated data (such as OLAP cubes), one may alternatively use Apache Kylin (Apache Software Foundation, 2020f) and Apache Druid (Apache Software Foundation, 2020g).

Data Processing

The types of data described in the previous section are subject to computational methods in order to extract, analyze, transform, retrieve, or classify data contained within various data stores. The number and kind of computational methods are defined only by the scope of the application of the platform. However, the requirements on the *DBL SmartCity* platform give rise to a number of core methods, such as the one shown in Fig. 8.

The figure shows a sequence of steps for (re)-generating a 3D tileset, whenever a new 3D building model is included for processing and interaction. The following sections describe two instances of this basic pipeline, using either OpenStreetMap (OSM) or IFC files as their starting point, in order to generate the corresponding 3D tileset.

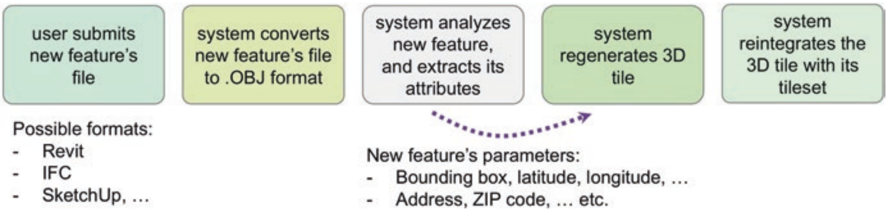


Fig. 8 A core data processing method: generating a feature in a 3D tileset

Data Pipeline A: From OSM to Streaming 3D Tiles

The Cesium 3D tiles streaming format enables users to interact with massive heterogeneous 3D geospatial datasets. However, 3D tiles must be generated beforehand from other types of geometric 3D data. The *DBL SmartCity* platform accordingly features a pipeline for generating streaming 3D tilesets of buildings at level-of-detail (LOD) level 100 exported from OpenStreetMap (OSM) (OpenStreetMap (OSM), 2020), which consists of the following steps:

- *Obtain a regional OSM extract (tile)*. This step results in a regional OSM extract, containing all entities (buildings, infrastructure).
- *Obtain initial OSM 3D buildings tile.* Filter the initial OSM extract, in order to obtain 3D building data only.
- *Convert OSM tile to OBJ tile.* Convert the filtered OSM extract tile into the open. OBJ Wavefront format.
- *Convert OBJ tile to a set of 3D objects.* Iterate over all objects in the OBJ tile, and then calculate/generate parameters for each object, such as its name, geographic coordinates, bounding box, and height. Follow up by exporting those parameters into a JSON "batch table" that lists parameters per each object.
- *Convert each OBJ "tile" into a streaming 3D tile.* Convert each OBJ "tile" into a proper Cesium 3D tile (a.b3dm file) as well as the associated *tileset.json* file, utilizing the batch tables generated in the previous step.
- *Combine 3D tiles.* Finally, merge separate tiles into a combined tileset, thus producing a generalized tileset.json file that reference each single tiles' tileset.json files as "external" tilesets.

Data Pipeline B: From IFC to Streaming 3D Tiles

In architecture, engineering and construction (AEC) industry, the IFC data model maintained by buildingSMART (2020) is a commonly used collaboration format in Building Information Modeling (BIM), which promotes interoperability by providing a *platform-neutral* and *open* format for building and construction data. IFC is currently registered as ISO standard 16739-1:2018, see (International Organization for Standardization (ISO), 2018).

An IFC file or model describes a BIM in all stages of the building's lifecycle, from its conception to demolition. An IFC model contains entities such as geometric shapes, building elements (e.g., walls, windows, doors), electrical elements (power outlets, switches), spaces, zones, furniture, and structural relations between aforementioned entities. An IFC model is furthermore governed by a set of schemas, with each of them expressing an aspect of the model, such as geometry, process, and structural elements.

Due to its well-defined structure, IFC files can be read and written by many software packages developed in industry and academia. Of note are open-source implementation for reading, parsing, and writing IFC code, such as IfcOpenShell (Krijnen, 2020), IFC for Revit (Autodesk, Inc., 2020), and the IFC++ (Bauhaus University, 2020). While semantically rich, IFC format is not suitable for encoding and interacting with large datasets of 3D building and infrastructure. To capitalize on the wide availability of rich and detailed IFC models, the steps for generating 3D tiles from IFC, using any of these packages, are similar to the sequence shown on Fig. 8, with the exception that IFC geometry is converted to the intermediary OBJ Wavefront format in step 3 instead.

Interacting with Data

The data contained within the data storage tier is available for retrieval, presentation, visualization, and modification. As a part of the platform, we have prototyped an initial browser-based application based on the Cesium virtual globe library (Cesium.com, 2020), with particular emphasis on its 3D tiles capability (Analytical Graphics, Inc., 2020).

Figure 9 shows the prototype's current graphical user interface, as well as how 3D models of buildings have been styled in real-time as a function of their height: tones of red color for tall buildings, green tones for medium-height buildings, and blue tones for low buildings. The screenshot additionally showcases the three types of data mentioned in the section on Data Typology and Storage:

- *Surface imagery.* This includes street names and building outlines, in this example provided by MapBox, Inc.
- *3D models of buildings.* Includes 3D models of buildings at LOD level 100, previously converted from an OpenStreetMap input file. In this case, the area covered by the OSM input file encompasses approximately a 40 × 40 square miles rectangle centered at the city of Atlanta, GA.
- *Secondary (derived) data.* This includes annotation data within the 3D scene ("John and Joyce Caddell Building" popup message), as well as alphanumeric data (time series of temperature data, legend data) within a separate GUI panel placed at the bottom of the screen.

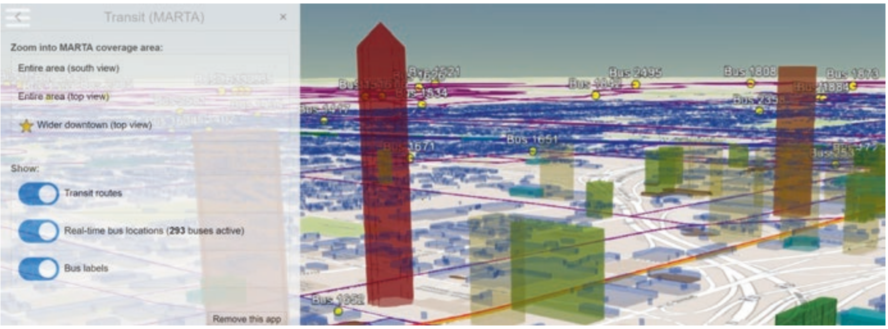


Fig. 9 A screen capture of the *DBL SmartCity* user interface

```
{
  "show" : "${zip} === '94301'",
  "color" : {
    "conditions" : [
      ["(${height} > 100.0)", "color('red')"],
      ["(${height} >  50.0)", "color('blue')"],
      ["(${height} >  10.0)", "color('green')"]
    ]
  }
}
```

Fig. 10 A snippet defining a visual style for 3D building models

Note that in order to support rich 3D visualizations of streaming geometrical and other data, Cesium provides means through which features can be dynamically (i.e., at runtime) *styled* by changing their color, transparency, and visibility using JSON and a small subset of JavaScript.

For instance, the styling code shown in Fig. 10 hides all the buildings currently present in the 3D scene, except those within the ZIP 94301 code area. Moreover, buildings will be rendered in red if they are taller than 100.0 m, in blue if taller than 50.0 m, and in green if taller than 10.0 m.

Interaction Design for the Web Client

Our approach to interaction design of the *DBL SmartCity* web client was inspired by existing interfaces, approaches, taxonomies, and classifications of interaction tasks reported in the research literature. For instance, Chaturvedi and Kolbe (2016) present an approach to integrating dynamic and sensor data with semantic 3D city models. Other "virtual globe" approaches to interacting with 3D building and geospatial data include applications such as NASA WorldWind (National Aeronautics and Space Administration (NASA), 2020), Google Earth (Google, Inc., 2020b), and

ESRI ArcGIS 3D Analyst (Environmental Systems Research Institute, Inc. (ESRI), 2020). Analytical Graphics Inc. (AGI) has recently introduced Cesium 3D tiles (Analytical Graphics, Inc., 2020), an open specification and reference JavaScript implementation for streaming massive heterogeneous 3D geospatial datasets. This technology allows third-party developers to build applications and systems that provide an ability to efficiently interact with voluminous 3D datasets that are typically generated and used in smart city and IoT scenarios.

Related work confirms the effectiveness of the Cesium 3D tiles specification. For example, Chaturvedi, Yao, and Kolbe (2015) successfully utilized the Cesium reference implementation in order to visualize, explore, and interact with large 3D city models integrated with time series of sensor data. Schilling, Bolling, and Nagel (2016) likewise discussed the conversion of CityGML models into Cesium 3D tiles format in order to efficiently stream large sets of city models at interactive rates. In another application of Cesium 3D tiles, Gan, Li, and Jing (2017) integrated digital surface models (DSM) of oblique photogrammetry with 3D tiles models, in order to enhance 3D presentations of buildings.

As for taxonomies of interaction tasks that have informed our graphical interface design, in an early and well-known classification, Shneiderman and Plaisant (2010, p. 539) recommended the interactive actions of "overview first, zoom and filter, then details on demand" acting over seven basic data types (1D, 2D, 3D, *n*-D, temporal, tree, and network data). In another classification, Brehmer and Munzner (2013) provided a beneficial and well-thought-out separation of abstract interactive visualization tasks into *why*, *what*, and *how* categories. Amar, Eagan, and Stasko (2005) presented a taxonomy of ten low-level visualization tasks, such as *retrieve value*, *compute derived value*, *sort*, and *correlate*, while Gotz and Zhou (2009) described an approach to tracking *insight provenance* (i.e., the rationale of the process behind insight), and a taxonomy of actions comprised of three major intent classes:

- *Exploration* actions (such as *filter*, *inspect*, *query*, *zoom*, *pan*, *sort*).
- *Insight* actions (i.e., *annotate*, *bookmark*, *modify*, *remove*).
- *Meta* actions (*delete*, *edit*).

In another pertinent article that informed our approach, Roth (2013a) presented a taxonomy of interaction primitives in the domain of computational cartography, whereby a task is represented by a combination of four entities:

- *Goal* (for instance, *retrieve information* about a geospatial object).
- *Objective* (for example, *find* the geospatial object in question).
- *Operator* (such as *filter*).
- *Operand* (the data state that was used for the operator filter, for example, the 3D scene itself, or a table listing geospatial objects).

According to the classifications and typologies above, we similarly group interaction operators in the *DBL SmartCity* platform into the following categories: *scope*, *express*, *navigate*, *examine*, and *edit*.

Scope operators. This family of interaction methods defines the current working set of data objects. This working set, once defined, can be examined and manipulated further by the user. The methods in this family include *search* (allow the user to search for preexisting objects of interest, and then possibly include a subset of search results into user's current working set) and *select* (allow the user to choose one or multiple data objects that can then be manipulated further).

Express operators. This family of interaction methods changes how a data object, such as a 3D building model, is displayed on screen, while preserving its *visual isomorph*, or "a representation of equivalent information in a different visual structure" (Roth, 2013b). Different representations, expressions, or visualizations can significantly affect human problem-solving performance (Hanrahan, 2009).

Navigate operators. This family of interactive methods allows the user to build up a "cognitive map" and understanding of the data objects being worked on (Cockburn, Karlson, & Bederson, 2009). Within the platform's web client, the three main navigation methods include *zoom*, *pan*, and *scroll*.

Examine operators. These interactive methods allow the user to further examine, inspect, or study the objects within the current scope, such as *details-on-demand*, *filter-out*, *filter-in*, *highlight*, *brush*, and *difference*.

Edit operators. This family of interactive methods allows the user to change or modify data objects, such as *create-object*, *modify-object*, *group-objects*, *ungroup-objects*, *undo*, *redo,* and *annotate*.

As an illustration of the *modify-object* method, Fig. 11 shows the generic sequence of steps for regenerating a 3D tile if the user decided to modify a feature of interest.

Plug-In "Apps"

The bundled web application implements a plug-in architecture, thus enabling third-party developers to develop and offer "apps." This plugin architecture for the client may be regarded as another aspect of the high-level requirement of modularity described in section "The *DBL SmartCity* Platform".

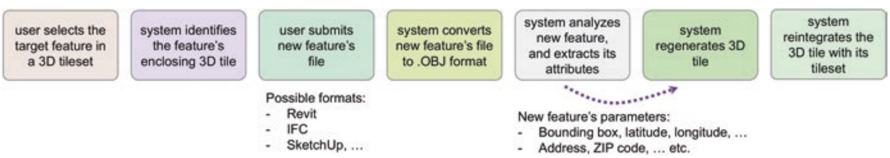


Fig. 11 The sequence of steps for editing a feature in a 3D tileset

Fig. 12 An example app for energy analytics

At the time of writing, the web client application features an "app" (or plug-in) for real-time public transit data, another app for real-time sensor monitoring, and yet another app for long-term data analytics related to energy use.

Figure 12 shows the energy modeling app that allows the user to visualize the proportions and amounts of both as-measured and simulated energy expenditure data, using pie charts and superposed line charts. Figure 13 shows an app that polls a public feed issued by the MARTA public transit agency based in Atlanta, GA, which allows the user to visualize real-time locations of active vehicles. The screenshot depicts a total of 299 passenger vehicles currently being in use, while displaying the agency's coverage area from a high attitude.

Support for Federated Nodes

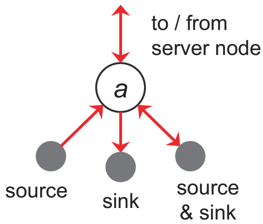
The architecture presented in Fig. 1 lends itself naturally to the *federation* of multiple *DBL SmartCity* nodes, by utilizing the message queuing functionality shown in Fig. 2. This functionality allows multiple running instances of the platform to unite into a loosely coupled federation in order to share and exchange information. To understand this aspect of the platform, subsystems within different tiers may be regarded as *IoT agents* and *IoT server nodes*.

Agents (see Fig. 14) are low-footprint data collection and data broadcasting modules meant to run on low-powered computing devices, which are connected to actual sources and sinks of IoT data (such as sensors and actuators). Agents can register with, send data to, and receive data from, multiple server nodes.

Server nodes encompass the middle six tiers shown in Fig. 1, i.e., all tiers except the lowest (IoT devices) and highest one (applications). That is, server nodes are either standalone computers or clusters of computers to which agents (at the lowest

Fig. 13 An example app for public transit information visualization

Fig. 14 An agent reads and writes from sources and into sinks of IoT data



level) and end applications (at the highest level) connect to, in order to store, process, and serve collected IoT data.

To support federation and syndication of multiple *DBL SmartCity* instances, server nodes can connect to other server nodes through their event streaming tier. (All message brokers, such as NATS and Kafka, provide functionality for interconnecting multiple instances of the same.) For example, a modest server can connect to a more powerful, upstream clustered server node that can store more data, or provide more powerful analytics capabilities.

To illustrate, Fig. 15 (left) depicts a simple network topology, where multiple IoT devices (each containing multiple sensors) are connected to a single, modest server node *n*. Figure 15 (right), on the other hand, presents a more complex network topology, where three simple server nodes are connected to a more powerful clustered server node on top that can store more data, or provide more advanced analytics capabilities. Other network topologies are possible, since any server node may connect to any other available server node.

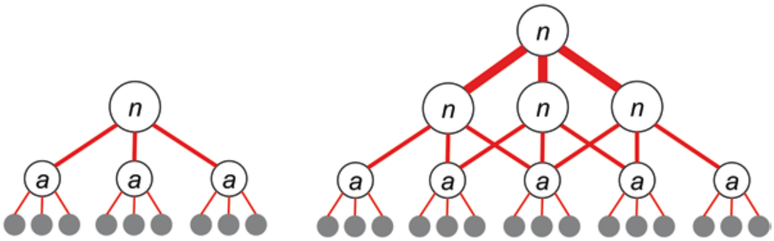


Fig. 15 Two examples of network topologies possible with the *DBL SmartCity* platform

Discussion

As mentioned in section "Introduction", one of our primary goals while conceptualizing the *DBL SmartCity* platform was the adoption of open data standards, open data transfer protocols, and open data formats in order to avoid interoperability and data exchange issues. We achieved this platform design goal by choosing and implementing standards and specifications issued by organizations that promote, develop, and maintain open standards and are active in the realms of geospatial data, BIM, and AEC. Such organizations include the Open Geospatial Consortium (OGC), Joint W3C/OGC Organizing Committee (JWOC), Open Source Geospatial Foundation (OSGeo), Cesium Consortium, Khronos Group, and buildingSMART.

For example, the Industry Foundation Classes (IFC) data model, which is maintained by buildingSMART2018 (buildingSMART, 2020) and commonly used as a collaboration format in BIM, promotes interoperability and openness in the AEC industry. Consider other examples: the Sensor Web Enablement (SWE) framework as well as the SensorThings API, also maintained by the OGC (2020b), provide an open standard to discover, bind/unbind, utilize, and share transducers (sensors, actuators) as well as associated data repositories.

As per our second stated design goal, the *DBL SmartCity* platform should be able to scale effortlessly with the increase of storage or compute demands. This aspect includes *interaction scalability*; client applications (web, desktop, mobile) must be able to effectively interact, even with very large datasets. We fulfill this requirement by adopting the streaming Cesium 3D tiles specification and reference implementation (Analytical Graphics, Inc., 2020). Moreover, *backend processing scalability* (the ability to scale from low to high processing demands) is fulfilled through the adoption of "big data" frameworks, such as Hadoop (Apache Software Foundation, 2020c) and the Node.js runtime environment technology (Node.js Foundation, 2020), as well as by adopting different database technologies that are suitable for a range of scenarios (from low to high data volumes).

As per our third stated goal, the platform should provide support for managing data typical for AEC, such as BIM, various kinds of 2D and 3D geometric data, and various types of geo-referenced data. Furthermore, the bundled web application should provide a framework for adding rich, powerful capabilities for interacting with such data. We ensure such support through the aforementioned formats (IFC, obj, glTF, b3dm) and the corresponding data processing pipelines.

With regard to the bundled web application, the two principal processes of *visualizing* (i.e., representing, rendering) sets of information and *interacting* with them are inextricably linked. They work synergistically in order to "scaffold the human knowledge construction process" (Pike, Stasko, Chang, & O'Connell, 2009). One may thus use the all-encompassing term "interactive visualization" to denote this tight coupling between interaction and visualization. The taxonomies we briefly surveyed offer comprehensive classifications and descriptions of the interaction tasks. Further research and development related to the platform will uncover additional needs, leading to new interaction capabilities, methods, and operators.

The fourth stated goal referred to the notion of *modularity*, namely the ability to decompose an entity into its subassemblies and components (Gershenson, Prasad, & Zhang, 2003). For instance, in programming languages, the word *module* refers to a "manageable portion" of the code (Chen, 1987), which allows one to build increasingly more complex modules from simpler ones. In terms of modularity, the *DBL SmartCity* platform was designed with the ability to substitute subsystems with other, functionally equivalent ones, yet which differ in some aspects, such as the ability to scale with increasing workload or data volume. For example, depending on the planned amount of data, the data storage subsystem may be implemented (in the order of increasing capacity) using SQLite, Postgres, or Cassandra.

Table 1 provides an overview of third-party, open-source technologies that can be used interchangeably within the *DBL SmartCity* platform, as well as a list of comparable commercial technologies and offerings.

Conclusions and Future Work

In this chapter we have presented the design rationale and architectural decisions behind *DBL SmartCity*, a recently-introduced open platform for managing large sets of urban, 3D, geo-referenced and IoT data. We have discussed how our architectural decisions affected and contributed to the platform's various aspects, such as its openness, scalability, interactivity, and modularity. In future work, we are planning to address the perceived limitations of the monolithic architecture by adopting the microservices approach using modern implementation and deployment technologies such as code and data containers, container orchestration, as well as various cloud computing platforms. We are also planning to conduct performance evaluations of the associated web application, results of which we will use to inform the next iteration of the platform's backend and user-facing functionalities.

Table 1 The modularity principle: interchangeable technologies within the *DBL SmartCity* platform

Tier	Sub-tier	Default	Alternatives (open-source)	Alternatives (commercial)
Data query	n.a.	Apache Drill	Apache (Impala, Spark SQL), Presto	Google (Dremel, BigQuery)
Big data	Analytics, OLAP	Druid	Apache Kylin	AtScale, Azure (Data Lake, HDInsight), AWS Redshift, Oracle Ess-base, Hyperion
	Processing	Apache (MapReduce, Spark)	Apache (MapReduce, Spark)	Oracle Big Data
	Data warehouse	HBase	Apache Cassandra, Greenplum	AWS Redshift, Azure (SQL Data Warehouse, Cosmos DB), Oracle Data / Warehouse Hub, Teradata, Informatica
	Files	HDFS (Linux)	GlusterFS, CephFS, BeeGFS	GoogleFS, AWS (S3, EFS, EBS), Azure (Blob, Files, Disk), GPFS, MapR-FS
RT data	Analytics	Druid	Apache Kylin	Azure (HDInsight, Time Series Insight, Power BI Embedded)
	Time series	TimescaleDB	Apache Cassandra, InfluxDB, KDB+, RRDtool, Graphite, OpenTSDB, Prometheus, Redis	Azure (Time Series Insights, Cosmos DB)
	Files	Local filesystem (XFS, Linux)	Other open-source GS filesystems	Commercial OS filesystems (Windows, macOS)
Events	Front-end	CLI, Angular	any (CLI, web, desktop, mobile)	Azure (Stream Analytics)
	Processing	NATS Streaming	Apache projects (Kafka Streams, Flink, Spark Streaming, Storm)	Azure (HDInsight, Stream Analytics, Databricks, Functions, Web-Jobs)
	Store	NATS	Apache Kafka, RabbitMQ, ActiveMQ, Kestrel, Redis	Oracle Event Hub
Agent mgmt	Front-end	CLI, Angular	any (CLI, web, desktop, mobile)	Azure IoT (CLI, web)
	Processing	Node.js	many (Java, Scala, Go, PHP, …)	Azure (IoT Hub), many
	Store	Postgres	many SQL/noSQL OSS databases (MySQL, Cassandra, HBase, …)	Azure (IoT Hub, Cosmos DB)

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Correction to: A Methodology for Participatory Planning of Smart City Interventions

Charalampos Alexopoulos, Loukis Euripidis, Dimitrios E. Kolokotronis, Nikolaos Vogiatzis, and Yannis Charalabidis

Correction to:
Chapter 8 in: E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37 https://doi.org/10.1007/978-3-030-61033-3_8

The co-authors' names of chapter 8 have been added to its opening page as it was published inadvertently without including it.

The updated version of this chapter can be found at
https://doi.org/10.1007/978-3-030-61033-3_8

E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3_17

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E. Estevez et al. (eds.), *Smart Cities and Smart Governance*, Public Administration and Information Technology 37,
https://doi.org/10.1007/978-3-030-61033-3