

The Urban Book Series

Simon Elias Bibri

Smart Sustainable Cities of the Future

The Untapped Potential of Big Data
Analytics and Context-Aware
Computing for Advancing Sustainability

 Springer

The Urban Book Series

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The Untapped Potential of Big Data Analytics
and Context-Aware Computing for Advancing
Sustainability

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The entire effort of your mind, soul, and heart working incessantly and in tandem, coupled with your grit and perseverance, is what it takes to succeed in your intellectual endeavors. But to sustain momentum for the long haul or to cope with unforeseen circumstances as part of life sometimes necessitates special people to come along at the right time.

To my beloved sister, Amina, for her wholehearted love, immeasurable moral support, and unfailing encouragement; and to whom I owe my life for the sacrifice she has made for me, as well as for her willingness and determination to sacrifice a lot more so that I can continue to thrive in my academic endeavors and thus nourish my passion for the pursuit of knowledge.

To Prof. Bjørn Olav Åsvold—the most humanly generous and thoughtful person I have ever been so lucky as to have known—whom I hold in highest regard in respect of

his authentic moral fiber, genuine humbleness, and matchless empathy, and to whom I am deeply indebted for his immense help, incredible kindness, insightful advice, and approachability. I stand in awe of him.

Preface

It is a profoundly erroneous truism...that we should cultivate the habit of thinking what we are doing. The precise opposite is the case. Civilization advances by extending the number of important operations, which we can perform without thinking about them.

—Alfred Whitehead

With new scientific discoveries and technological innovations, most notably big data analytics and context-aware computing as powerful drivers for the next wave of urban analytics and planning, we hope to fulfill Alfred Whitehead's maxim of achieving progress through the increasing automation and intelligence of solutions for overcoming the challenges of sustainability and urbanization in the context of smart sustainable cities of the future. To put it differently, noteworthy advances in data science, computer science, and complexity science and the related technologies and their novel applications inevitably bring with them wide-ranging common visions on how cities as social fabrics epitomizing the microcosm of the world in terms of encapsulating in miniature its characteristic features as to environmental change, economic development, and social transformation will evolve in the future. They moreover open entirely new windows of opportunity for the application of engineering- and computing- inspired solutions to once intractable and wicked urban problems. This relates to the role of science-based technology in modern society in terms of advancing almost all human endeavors and activities. More importantly, the primary goal of the construction of the techno-urban vision of smart sustainable cities is to provoke thought and discussion, to create fertile insights, to generate new opportunities, to depict possible futures, and crucially, to align key stakeholders and mobilize resources into the same direction.

Key Aims and Major Themes

This scholarly book has been written as a timely and comprehensive reference for several classes of readers who are interested in the interplay between computing, ICT, sustainable development, sustainability science, urbanization, and urban

design and planning. It is therefore intended to help to explore the field of smart sustainable cities in its complexity, heterogeneity, and breadth, the many faces of a topical subject that is of major importance for the future, and that encompasses so much of modern urban life in an increasingly technologized, computerized, and urbanized world. Indeed, sustainable urban development is currently at the centre of debate in light of several ICT visions becoming concurrently achievable and deployable computing paradigms, and shaping the way cities will evolve in the future and tackle complex challenges with support of advanced technologies. Widely acknowledged as the most influential and enticing strands of contemporary computing and ICT, big data analytics and context-aware computing are certainly reshaping and enriching our experiences of how cities can function and be managed, planned, and developed. They are offering many new and unique opportunities for more informed and strategic decision-making with respect to our knowledge of how fast and best to address the challenges of sustainability and urbanization that are facing major cities of the world, and that will continue to grow in the years ahead. Therefore, there is a wide recognition and much enthusiasm about the immense possibilities created by new and more extensive sources of urban data to effectively monitor, understand, analyze, and plan cities to strategically improve their contribution to the goals of sustainable development through such processes as automation, optimization, control, management, strategy development, and policy design.

The primary goal of this book is to help readers view the challenges of sustainability and urbanization in the context of smart sustainable cities of the future from the perspective of big data analytics and context-aware computing. It is also to understand the fundamental principles of extracting useful knowledge and inferring context knowledge from large masses of data for enhanced decision-making and insights pertaining to urban operational functioning, management, planning, and development for the purpose of addressing those challenges. This book involves innovative computer-based and data-analytic research on smart sustainable cities as complex and dynamic systems. It provides theoretical and applied contributions fostering a better understanding and development of such systems and the synergistic relationships between the underlying physical and informational landscapes. It offers contributions pertaining to the ongoing development of computer-based and data science technologies for the processing, analysis, management, modeling, and simulation of urban data and the associated application in the operating and organizing processes of urban life—urban systems—that will advance different aspects of sustainability and contain the multidimensional effects of urbanization. Accordingly, this book focuses on city-related disciplines and sciences in relation to big data and context-aware technologies and their novel applications. In this respect, I give special importance to the general principles of such disciplines and sciences in terms of how computer science and data science are reshaping them and facilitating their amalgamation in the context of sustainability thanks to recent discoveries in urban analytics and computing—that make it possible to acquire a better understanding of urban systems and to enable an effective coordination of urban domains, coupled with the breakthroughs at the level of the core enabling

technologies underlying big data analytics and context-aware computing. These include sensing technologies, data processing platforms, middleware architectures, cloud and fog computing infrastructures, and wireless communication networks. Such discoveries and breakthroughs are making it increasingly possible to build novel systems based on that understanding and coordination for the purpose of strategically advancing the contribution of smart (and) sustainable cities to the goals of sustainable development.

To facilitate embarking on exploring the realm of smart sustainable cities of the future, I have designed this book around three related aims: to help readers gain essential underpinning knowledge about the topic of smart sustainable cities; to help them develop a deeper understanding of this emerging techno-urban phenomenon as they make connections between their own understandings of smart and sustainable cities and emerging theoretical, analytical, and applied concepts; and, more importantly, to encourage them to take part in the ongoing debate about smart sustainable urban development. This is indeed gaining special importance in, and whose prominence will increase throughout, the twenty-first century, as cities across the globe are increasingly facing intractable and wicked problems due to the imminent challenges of sustainability and urbanization.

Subject Treatment and What Makes the Book Unique in its Field

This book is the first of its kind with respect to the approach into probing the new techno-urban phenomenon and flourishing field of smart sustainable cities—based on a uniquely holistic and interdisciplinary perspective. In response to the growing need for an inclusive analysis or a multi-perspectival approach to the study of the phenomenon of smart sustainable cities, this book deals with the interdisciplinary aspects of the rapidly evolving field of smart sustainable urban planning and development in the context of technologically and ecologically advanced nations. This field is still in its early stages and the subject matter draws upon a set of influential theories and powerful discourses with practical applications—i.e. the application of urban design and planning, sustainable development, sustainability science, computer science, data science, and ICT as a foundation for future urban practices. In view of that, this book adopts a unique and compelling approach to cross-disciplinary integration entailing a variety of theoretical, applied, scientific, and technological perspectives drawn from computer science, data science, complexity sciences, ICT, socio-technical studies, environmental sciences, innovation science, urban studies, policy, philosophy, ecology, and sociology. This is meant to achieve a broader understanding of the multifaceted phenomenon of smart sustainable cities, and also constitutes a means to facilitate collaboration among and between an array of academic and scientific disciplines for the primary purpose of generating the kind of interactional knowledge necessary for a more integrated perspective on the topic of smart sustainable cities. This is a core contribution that

supports the foundational ethos of interdisciplinarity associated with the blossoming field of smart sustainable urban planning and development.

In specific terms, the focus in this book is on exploring the potential of ICT of the new wave of computing to provide the technological infrastructures, solutions, and approaches necessary for advancing the contribution of sustainable urban forms to the goals of sustainable development based on an effective integration of the design and planning concepts and principles of such forms with big data analytics and context-aware computing in terms of the underlying core enabling technologies and their novel applications and services being offered by smart and smarter cities. While big data analytics and context-aware computing play a crucial role for smart sustainable cities, it is worth pointing out that other ICT potentials (robotics, cybernetics, etc.) also have a role to play in this regard. However, the use of big data analytics and context-aware computing as prerequisite technologies for realizing ICT of the new wave of computing entails that smart sustainable cities will take the form of constellations of instruments—architectures, platforms, applications, and computational and data analytics capabilities across many spatial scales that are connected through wirelessly ad hoc and mobile networks with a modicum of intelligence. These networks can provide and coordinate continuous data on different features of urban domains (activities, processes, structures, citizens, and entities) in terms of the flow of decisions about the physical, infrastructural, operational, functional, and socioeconomic forms of smart sustainable cities. This constitutes a fertile environment conducive to monitoring, understanding, analyzing, operating, managing, and planning smart sustainable cities. This is about leveraging their informational landscape in addressing the challenges of sustainability and urbanization. One of the salient driving factors for urban design and planning embracing the wave of smartness lies in the immense opportunities being created through the utilization of the innovative solutions and sophisticated methods increasingly enabled by big data and context-aware technologies that are being designed and applied for supporting the goals of sustainable development. In all, this book offers a novel, fresh, and all-encompassing approach to the exploration of smart sustainable cities as an integrated and holistic urban development strategy. In doing so, it combines academic, scientific, and practical relevance with urban, technological, social, and environmental analysis, supported with critical and reflective thinking.

Originality and Value

Up till now, no comprehensive book has, to the best of one's knowledge, been produced elsewhere—as to systematically exploring the field of smart sustainable cities in terms of seamlessly amalgamating the design and planning principles of sustainable urban forms with the novel applications of ICT of the new wave of computing for urban sustainability, i.e. merging the physical and informational landscapes of smart sustainable cities in ways that strategically assess, improve, and

sustain their contribution to the goals of sustainable development. Nor has any book approached the topic from the perspective of integrating data science, computer science, complexity science, and the social sciences—more specifically, the untapped potential of big data analytics and context-aware computing for overcoming the imminent challenges of sustainability and urbanization in the context of smart sustainable cities as complex systems. In this regard, this book combines big data and context-aware technologies and their novel applications for the sheer purpose of harnessing and leveraging the disruptive and synergetic effects of ICT on modern cities in the needed transition towards, and the advancement of, sustainable development. Especially, the effects of such technologies reinforce one another as to their efforts for transforming the processes operating and organizing urban life in a sustainable way by integrating data-centric and context-aware solutions to enhance and integrate urban systems and to facilitate collaboration and coordination among urban domains.

This seminal work provides the necessary material to inform relevant research communities of the state-of-the-art research and the latest development in the area of smart sustainable urban planning and development, as well as a valuable reference for scholars and practitioners who are seeking to contribute to, or already working toward, the development, deployment, and implementation of smart sustainable cities based on big data analytics and context-aware computing. In this respect, the upshot of this book enables researchers to focus their work on the identified challenges pertaining to and the existing gaps between smart cities and sustainable cities as established urban development strategies. Practitioners can use the outcome to identify common weaknesses and alternative solutions in sustainable urban planning and development initiatives and endeavors. While this book can best be seen as being aimed at those with a background in both computation and urban planning, it is primarily from a computation angle (it would be more appropriate for giving computer scientists a vantage on planning than giving planners a vantage on computation), yet with much valuable knowledge of relevance to urban planners.

Furthermore, its strength lies primarily in the topicality of the issues it deals with and the meaningfulness of the subjects it covers. Specifically, it covers topics of immediate relevance and importance owing to their relation to the contemporaneous phenomena of sustainable development, sustainability, urbanization, ICT, ubiquitous computing, and data science, in addition to comprising many aspects of future city life in terms of life quality, environmental quality, resource efficiency, mobility and accessibility enhancement, and so on. These are associated with the ongoing endeavors and initiatives for smartening up urban sustainability and integrating its dimensions.

Intended Readership

Smart Sustainable Cities of the Future is intended for several classes of readers, namely students, researchers, academics, data scientists, computer scientists, technologists, ICT experts, urban planners, urbanists, engineers, architectural designers, urban professionals, urban policy analysts and makers, and decision makers and leaders, whether they are new or already working or involved in the area of smart sustainable urban planning and development, as well as for all of those interested in a wide-ranging overview of contemporary urban innovations in the field. Specifically, I have written this book with two kinds of readers in mind. First, I am writing to students taking graduate and postgraduate courses or pursuing Master's and Ph.D. programs in the areas of smart cities, sustainable cities, urban design and planning, urban computing, urban informatics, urban science, urban sustainability, sustainable urban management, and so forth. Those familiar with smart cities and sustainable cities and the relationship between these two concepts or urban development approaches will certainly get more out of this book, and find much more that appeals to them in it than those without that grounding. However, those with more limited knowledge are supported with detailed explanations of the relevant conceptual, theoretical, discursive, and applied foundations with reference to the field of smart sustainable urban planning and development. This is meant to appease the uninitiated reader. Second, I anticipate that this book will be a useful resource for all of those involved or with interest in smart sustainable urban planning and development (scholars, scientists, practitioners, decision makers, futurists, etc) that are looking for an accessible and essential reference as to the interplay between the scientific and technological developments and the physical, social, and environmental dimensions of smart sustainable cities. In all, people in many academic disciplines and professional fields will find the wide-ranging coverage of the diverse strands comprising, and the multiple perspectives associated with, the flourishing field of smart sustainable cities to be of interest and value. My hope is that this book will also be suited to people of other societies than technologically and ecologically advanced nations.

Perspectives and Prospects

This book benefits indirectly from the work of many people working within, and at the intersection of, the fields of smart cities and sustainable cities. Thus, I am indebted to other writings in the sense of inspiring me into a quest for the immense opportunities created by endeavoring to integrate smart cities and sustainable cities as urban development strategies to achieve the required level of sustainability under what is labeled “smart sustainable cities of the future” in an increasingly computerized and urbanized world. This has led me to espouse an intellectually distinctive approach into writing this book so that it can offer a tremendous value with

auspicious effects and be differentiated from other books on the topic on focus with regard to their emphases and scopes of scholarship, as well as to their research perspectives. This is manifested in identifying and leveraging the potential of explicitly bringing together the smart city and sustainable city endeavors in a form of a holistic urban development strategy, and in focusing on and amalgamating big data analytics and context-aware computing specifically. While this book has an ambitious goal, clearly it is not possible to deal with every aspect of smart sustainable cities in a single book, nor can it cover all of the chosen topics in equal depth. Nevertheless, it will be a great asset to relevant research and scientific communities, as well as to those who are interested in the notion of smart sustainable cities as a new techno-urban innovation or vision.

This book highlights the increasing urgency to link future discoveries in computing and emerging developments in ICT with the agenda and goals of sustainable development in the realm of smart sustainable cities, a promising urban development approach that emphasizes decoupling urban well-being and health and the quality of life of citizens from the energy use and concomitant environmental risks associated with urban operations, functions, services, designs, and policies. Indeed, current and future investments in ICT of the new wave of computing ought to be justified by environmental concerns and socioeconomic needs, thereby enabling livable and healthy human environments in conjunction with minimal demand on resources and minimal environmental impacts—rather than by sheer technical advancement and unjustified industrial competitiveness. What is mostly needed nowadays are techno-urban innovations and visions that are not driven by distant and overblown computing and ICT research agendas focused mainly on technological superiority motivated by short-term profits, narrow outlooks, and unsustainable disruptive effects—but rather driven by the pursuit of the persistent delivery of robust solutions for promoting urban sustainability and stimulating research opportunities within the field.

Furthermore, this book expects to elicit fertile insights and provide new perspectives in the event of amalgamating big data analytics and context-aware computing as advanced forms of ICT in the context of urban sustainability. This is meant to bring people from different academic disciplines and professional fields or working on cross connections of computing, ICT, sustainability science, sustainable development, and urban design and planning (including scholars, academics, researchers, scientists, experts, planners, architects, engineers, administrators, and policy makers) on a common platform to design, develop, disseminate, and concretize new ideas and concepts to significantly improve the field of smart sustainable cities and to promote related programs and initiatives based on big data analytics and context-aware computing.

Additionally, I consider that this book provides a form of grounding for further discussions to debate over the point that ICT of the new wave of computing has disruptive, substantive, and synergetic implications, in particular on forms of urban functioning, management, and planning that are necessary for urban sustainability practices in the future. This book also presents a basis for encouraging in-depth research on smart sustainable cities, thorough qualitative analyses, and empirical

studies focused on establishing, uncovering, and substantiating the assumptions underlying the substance behind the smart wave of sustainable urban planning and development initiatives and endeavors in an increasingly computerized and urbanized world.

Finally, I believe that I have achieved an important goal with this book—by creating a valuable and strategic resource for the research community and industry involved in the domain of smart sustainable urban development. Especially, I believe that there is an urgent need for a comprehensive book on smart sustainable cities given that the field is remarkably heterogeneous with a large number and wide variety of research questions and opportunities yet to explore. I will be pleased if this book contributes to a better understanding of smart sustainable cities of the future, and helps in stimulating their development and implementation. All in all, I hope that this book will be enlightening, thought-provoking, and, more importantly, making good reading for the target audience. And ultimately, the first edition will be well received.

Trondheim, Norway
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Simon Elias Bibri

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This scholarly book as an integral part of my ongoing Ph.D. research is the fruit of rich learning experiences and valuable intellectual pursuits involving many people whom I have had the pleasure and privilege to meet during my academic studies in Sweden. I hope that our paths will cross again in the future. I am more indebted than I can possibly acknowledge to the people that have particularly contributed directly, indirectly, or unknowingly to my knowledge enrichment and intellectual development. Also, I am greatly thankful to those who have supported me throughout my academic journey, encouraged me to pursue the path of scientific research, believed in my intellectual abilities, and inspired me to become an academic author. I wish next to offer my most heartfelt thanks to those who have contributed directly and indirectly to this book, making it such an enjoyable and momentous intellectual experience.

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helped me become more self-reflective and self-critical in order to broaden my perspective of thought and thus enhance my research work. Their diverse background and research interests give their inputs a distinct intellectual flavor in respect of the approach to my research topic.

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- Smart city approaches (ambient city, ubiquitous city, sentient city, real-time city, etc.)
- Sustainability transitions and socio-technical shifts
- Green innovation and knowledge-intensive entrepreneurship
- Philosophy and sociology of scientific knowledge
- Social construction and shaping of science-based technology
- Technological and national innovation systems
- Sustainable business model innovation
- Technology, innovation, and environment policy.

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1. *The Human Face of Ambient Intelligence: Cognitive, Emotional, Affective, Behavioral and Conversational Aspects* (523 pages), Springer, 07/2015.
2. *The Shaping of Ambient Intelligence and the Internet of Things: Historico-epistemic, Sociocultural, Politico-institutional and Eco-environmental Dimensions* (301 pages), Springer, 11/2015.

3. Smart Sustainable Cities of the Future: The Untapped Potential of Big Data Analytics and Context-Aware Computing for Advancing Sustainability (650 pages), Springer, 2018.
4. Unprecedented Shifts in the Philosophy and Sociology of Sustainability Science in the Exabyte Age: The Unique Potential and Power of the Big Data Deluge (350 pages).