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Simon Elias Bibri

Big Data Science and Analytics for Smart Sustainable Urbanism

Unprecedented Paradigmatic Shifts and Practical Advancements

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ISSN 2522-8714 ISSN 2522-8722 (electronic)
Advances in Science, Technology & Innovation
IEREK Interdisciplinary Series for Sustainable Development
ISBN 978-3-030-17311-1 ISBN 978-3-030-17312-8 (eBook)
https://doi.org/10.1007/978-3-030-17312-8

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

To Fatima Zahrae Gouttaya for her generosity and good nature, knowing all my story and living it with me, making the good times unforgettable, and becoming my family. What sheer bliss to have someone to lean on and to share daily experiences, intellectual passions, and life aspirations with. I admire her for her integrity, moral fiber, intellectual curiosity, native wit, and sense of humor, as well as for her distinct combination of optimism, passion, perseverance, and determination as to pursuing long–term goals in life.

Preface

Key Aims and Themes

This timely and multifaceted book is concerned with the complex interplay of the scientific, technological, and social dimensions of the city, and what it entails in terms of the ensuing systemic outcomes pertaining to sustainability as informed and underpinned by data-driven smart urbanism. In concrete terms, it explores the interdisciplinary and transdisciplinary field of smart sustainable urbanism and the unprecedented paradigmatic shifts and practical advances it is undergoing in light of big data science and analytics and the underlying advanced technologies. The scholarly, practical, and futuristic strands of this rapidly burgeoning field are currently at the center of debate due to the emerging paradigmatic shift in science development and epistemic shift in knowledge production brought about by big data science and analytics, coupled with their salience to the fundamental change in the way the city is operated, managed, planned, designed, developed, and governed. In this respect, big data science and analytics as a new area of science and technology is seen as a major factor that determines the way the city will tackle the kind of special conundrums, wicked problems, intractable issues, and complex challenges it embodies through a multitudinous array of alternative solutions in the form of novel applications and sophisticated methods informed by advanced scientific and scholarly research. This consequently determines how the city will evolve in the future under the multiple processes of, and pathways towards achieving, smart sustainable urban development. In a nutshell, developments in science and technology fundamentally alter the way people live, with profound effects on all spheres of society in terms of advancements and innovations.

This book aims to help view the challenges of sustainability and urbanization as well as the alternative approaches to tackling them from the perspective of big data science and analytics through the lens of smart sustainable cities as a leading paradigm of urbanism and a manifestation of social evolution. It also intends to facilitate the understanding of the fundamental principles of big data computing with respect to the automated extraction of useful knowledge from large masses of data for enhanced decision-making and deep insights pertaining to urban operational functioning, management, planning, design, and development for the primary purpose of addressing those challenges. Indeed, this book is about data-driven smart sustainable urbanism in the sense of exploiting, harnessing, and leveraging the unfolding and soaring deluge of urban data through advanced analytics to discover new knowledge in the form of applied intelligence intended for enhancing and optimizing urban operations, functions, services, designs, strategies, and policies across multiple urban domains in line with the goals of sustainable development in a rapidly urbanizing world.

This book involves innovative, up-to-date big data science and analytics research related to smart sustainable urbanism, that is, theoretical, technological, and interdisciplinary and transdisciplinary studies that make up the field of data-driven smart sustainable urbanism in terms of practice. Accordingly, it provides theoretical and applied contributions fostering a better understanding of this approach to urbanism and the synergistic relationship between the related practices. With respect to the latter, at the core of smart sustainable urbanism is the

synergy between urban operational functioning, planning, design, and development in terms of their interaction or cooperation to produce a combined effect greater than the sum of their separate effects. This entails using big data computing and the underpinning technologies as an enabler for such synergy and a determinant of its outcomes. Further, this book offers contributions pertaining to the ongoing development of urban intelligence functions and related simulation models and optimization and prediction methods as innovative solutions for how smart sustainable cities can be monitored, understood, and analyzed so as to be effectively operated, managed, planned, designed, developed, and governed in line with the goals of sustainable development. Applying urban intelligence functions as new conceptions of the way such cities function and utilize complexity science, data science, and urban science in fashioning new powerful forms of urban simulation models and optimization and prediction methods that generate urban forms and structures that improve sustainability, efficiency, resilience, and the quality of life is crucial to dealing with such cities as complex systems and dynamically changing environments. In short, it provides in-depth coverage of the latest advances in the field of smart sustainable urbanism in the wake of the big data revolution.

To facilitate embarking on exploring the field of smart sustainable urbanism and the unprecedented shifts and advances it is undergoing, I have designed this book around three related aims: to help readers gain essential underpinning knowledge about the topic of smart sustainable urbanism, especially in terms of its scientific, scholarly, and practical dimensions; to enable them develop a broader understanding of this flourishing field as they make connections between their own understandings of the current urban challenges and the ongoing urban transformations, on the one hand, and the emerging shifts instigated by big data science and analytics, on the other hand; and, more importantly, to encourage them to take part in the ongoing debate about smart sustainable urbanism in the big data era and the ensuing datafication of the city. The data avalanche is here.

Uniqueness and Subject Treatment

This book is the first of its kind with respect to the topicality of the issues it addresses, the contemporaneous phenomena it is concerned with, and the unprecedented shifts and advances it covers in the context of smart sustainable urbanism in the era of big data science and analytics. This unique amalgam is indeed deemed relevant and salient in light of the changes taking place in the urban world. We are currently in the midst of a new wave of enthusiasm for scientific urbanism of a historically unparalleled kind inspired by the big data revolution and carrying wide-ranging implications for the practice of smart sustainable urban planning, design, and development. This is manifested in us experiencing the accelerated datafication of the city in a rapidly urbanizing world and witnessing the dawn of the big data era not out of the window, but in everyday life. Our urban everydayness is entangled with data sensing, data processing, and communication networking, and our wired world generates and analyzes overwhelming and incredible amounts of data. This allows for, over sufficiently long periods of time, extracting changes to the structure and form of the city and the way people behave in the form of useful knowledge and valuable insights associated with applied intelligence. The modern city is turning into constellations of instruments and computers across many scales and morphing into a haze of software instructions, which are becoming essential to the operational functioning of the city. The datafication of spatiotemporal citywide events has become a salient factor for smart sustainable urban planning, design, and development.

This book is also unique in regard to the approach to studying the field of smart sustainable urbanism—based on a uniquely holistic perspective. Accordingly, it approaches the topic of smart sustainable urbanism from an interdisciplinary and transdisciplinary perspective while adopting a compelling approach to cross-disciplinary integration and fusion involving diverse scientific and academic fields, notably data science, urban science, urban informatics,

complexity science, environmental engineering, sustainability science, and systems science, as well as urban planning and design, sustainable development, philosophy, and the social sciences. This is meant to achieve a broader and more inclusive understanding of the phenomenon of smart sustainable urbanism by facilitating collaboration among and between an array of disciplines for the primary purpose of generating the kind of interactional and unifiable knowledge necessary for such understanding. This is a core contribution that supports the foundational ethos of interdisciplinarity and transdisciplinarity characterizing the research field of smart sustainable urbanism. Interdisciplinarity and transdisciplinarity have become a widespread mantra for research within diverse fields, accompanied by a growing body of scientific and scholarly publications. On the whole, this book offers a novel, fresh, all-encompassing approach to the exploration of smart sustainable urbanism as a holistic and integrated paradigm of urban planning, design, and development. In doing so, it combines scientific, academic, and practical relevance with philosophical, social, ethical, and environmental analyzes, supported with critical and reflective thinking.

Originality and Value

Up till now, no multifaceted book has, to the best of one's knowledge, been produced elsewhere—as to exploring smart sustainable urbanism and examining the historically unprecedented shifts and advances this blossoming field is undergoing as a result of the uptake and diffusion of big data science and analytics and underpinning technologies. Nor has any book approached the topic from the perspective of integrating and fusing these scientific fields: data science, urban science, complexity science, systems science, sustainability science, and environmental engineering—with a result that both yields new ideas by thinking across disciplinary boundaries as well as exceeds the simple sum of each discipline. This can be accomplished by combining different analyzes, using insights and methods in parallel and conjunction, and spilling over and blurring boundaries. Indeed, there is a growing need to fill the shortage urban research is facing nowadays in key scientific respects, and to advance urban sustainability science as to tackling the dilemma of the wicked problems associated with urbanism in terms of planning, design, and development. In particular, urban sustainability science requires a decisive, radical change in the way science is undertaken and developed. Such change is, in fact, what data-intensive science is about. Moreover, beyond the need for a stronger interdisciplinary and interdisciplinary lens, urban research needs to be adequately directed to real-world problem applications pertaining mainly to sustainability and urbanization. Urban research is still segmented by disciplinary boundaries when urban transformations demand truly holistic urban research, and whereas solutions to global problems require integrated (cross-disciplinary) knowledge.

This seminal work provides the necessary material to inform the research communities concerned with the unprecedented shifts and advances that smart sustainable urbanism is going through and with the state-of-the-art research and the latest development in this area in light of big data science and analytics. It also provides a valuable reference for scholars and practitioners who are seeking to contribute to, or already working towards, the development and implementation of smart sustainable cities as a leading paradigm of urbanism based on big data computing and the underpinning technologies. In this respect, the upshot of this book enables researchers to focus their work on the extreme fragmentation and weak connection between sustainable cities and smart cities as landscapes and approaches, respectively, while embracing the emerging shifts pertaining to smart sustainable urbanism to mitigate or overcome such issues by realizing smart sustainable/sustainable smart cities. Practitioners can use the outcome of this book to identify common weaknesses, flaws, and drawbacks in smart sustainable urbanism projects and initiatives and then deal with them through devising alternative solutions on the basis of what big data computing and the underpinning

technologies have to offer as novel applications and sophisticated approaches. These pertain to new ways of optimizing and enhancing urban operational functioning, planning, design, and development in response to the challenges, or in line with the goals, of sustainable development.

While this book can best be seen as being aimed at those with a background in both urban science and sustainable urbanism, it is primarily from an urban science angle. That is to say, it would be more appropriate for giving urban scientists a vantage on sustainable urbanism than giving sustainable urbanists a vantage on urban science. Nonetheless, it contains value-laden knowledge and technology of high relevance to sustainable urbanists.

Intended Readership

Big Data Science and Analytics for Smart Sustainable Urbanism is intended for several classes of readers, including students, researchers, academics, data scientists, urban scientists, urban informaticians, philosophers of science, social scientists, futurists, technologists, ICT experts, urbanists, planners, engineers, architectural designers, built and natural environment specialists, and policy analysts and makers, whether they are new to or already involved in smart sustainable urbanism as a field for research and practice. It is also intended for all of those interested in an overview covering an extensive range of topics pertaining to the role of big data science and analytics in catalyzing the emerging shifts and advances that are of an unprecedented kind as related to both this field as well as the other fields or disciplines concerned with data-intensive science.

Specifically, I have written this book with two kinds of readers in mind. I am writing to students taking graduate and postgraduate courses or pursuing Master's and PhD programs in the areas of sustainable cities, smart cities, smart sustainable cities, urban planning and design, sustainable urban development, environmental engineering, urban informatics, urban science, sustainability science, and so forth. Those readers already familiar with sustainable cities and smart cities as leading paradigms of urbanism and their relationship as both landscapes and approaches in the context of sustainability and with the growing role of big data computing and the underpinning technologies in improving and advancing their contribution to the goals of sustainable development will certainly get much more out of this book and find much more that appeals to them in it than those lacking that grounding. Nevertheless, those readers with limited or without knowledge in this particular area are provided and supported with a detailed explanation and discussion of the relevant conceptual, theoretical, disciplinary, discursive, and practical foundations with reference to the integrated field of smart sustainable urbanism and the underlying scientific and technological components. This is meant to appease the uninitiated readers. Second, I believe that this book will be a very useful resource for all of those involved or with interest in smart sustainable urbanism (including scholars, scientists, practitioners, intellectuals, technology forecasters, decision makers, etc.) that are looking for an accessible and essential reference with respect to the interplay between big data science and analytics as a new area of science and technology and smart sustainable urbanism as a rapidly emerging field. Overall, people in many scientific and academic disciplines and professional fields will find the unique coverage of the scientific and epistemic shifts and scholarly and practical advances related to this flourishing field (as well as other fields and disciplines) as brought about by the materialization of big data science and analytics and the increasing adoption and use of the underlying core enabling technologies to be of great value and usefulness. My hope is that this book will also be of interest to people of other countries than ecologically and technologically advanced nations.

Perspectives and Prospects

This book benefits indirectly from the work of many people working within the field of smart urbanism, sustainable urbanism, smart sustainable urbanism, sustainable smart urbanism, or at the intersection of urban science and urban sustainability, and focusing on the transformational effects of big data science and analytics on urbanism. Thus, I am indebted to other scientific and scholarly writings in the sense of inspiring me into a quest for the great opportunities enabled by endeavoring to explore the emerging field of smart sustainable/sustainable smart urbanism along with the emerging shifts it is undergoing because of big data science and analytics. 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 in the field and be differentiated from other books on the topic of smart sustainable/sustainable smart urbanism, if any, with regard to their focus and scope of scholarship, as well as to their approach to exploration. While this book has an ambitious goal, clearly it is not possible to deal with every aspect of and shift in such urbanism in a single book, nor can it cover all of the chosen topics in equal depth. Nevertheless, it will be a great asset to the relevant scientific and scholarly communities, as well as to those who are simply interested in urban transformations enabled by technological innovations.

This book highlights the increasing urgency to merge big data computing and the underpinning technologies as recent discoveries and innovations as part of urban science with urban sustainability and sustainability science in the research and applied domain of smart sustainable urbanism. The strength of this integrated approach lies in using the most advanced strategies and methods for decoupling the overall wellbeing and health of the city 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, the current and future investments in big data computing and the underpinning technologies ought to be justified by environmental concerns and socioeconomic needs, 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 urbanism approaches and innovations that are not driven by distant and overblown ICT of pervasive computing research agendas focused mainly on technological superiority motivated by short-term profits, narrow outlooks, and unsustained disruptive effects—but rather by the pursuit of the persistent delivery of robust solutions for improving and advancing urban sustainability and stimulating research opportunities in this direction. Especially, big data science and analytics is a means for science and society to control uncertainty and to make discoveries in relation to sustainability, among others. As long as there is uncertainty and intractability in the world, there is a need for big data science and analytics,

In addition, this book expects to elicit novel insights and spark new perspectives as a result of integrating and harnessing the emerging shifts associated with smart sustainable urbanism. The primary intent is to bring scholars and practitioners closer together from different disciplines and professional fields, or who are working on cross connections of data science, urban science, sustainability science, and urbanism, to develop, concretize, and disseminate new ideas for advancing the field of smart sustainable urbanism as well as promoting related projects, programs, and initiatives based on big data computing and the underpinning technologies.

Furthermore, I consider that this book represents a basis for further discussions to debate the point that big data science and analytics and the underlying core enabling technologies have disruptive, substantive, and synergetic effects, particularly on forms of urban planning, organization, design, and development that are required for future forms of smart sustainable urbanism. In the meantime, this book seeks to encourage in-depth research, thorough qualitative analyzes, and empirical investigations focused on establishing, substantiating, or

challenging the assumptions and claims made by the advocates of big data science and analytics with regard to advancing sustainability.

Finally, I believe that I have achieved an important goal with this book—by creating a valuable, strategic resource for the scientific and scholarly communities and the industries involved in the field of smart sustainable urbanism. Especially, there is an urgent need for a multifaceted book on smart sustainable urbanism given that the field is remarkably heterogeneous with a large number and wide variety of unaddressed and unsettled questions and unexplored and promising opportunities. I will be pleased if this book contributes to a better understanding of the topic under investigation, and, more importantly, stimulates the development and implementation of smart sustainable cities on the basis of big data computing and the underpinning technologies and thereby mitigates or overcomes the extreme fragmentation of and the weak connection between sustainable cities and smart cities as landscapes and approaches, respectively. All in all, I hope that this book will be enlightening, thought-provoking, and making good reading for the target audience. And ultimately, the first edition will be well received.

Trondheim, Norway
October 2018

Simon Elias Bibri

Acknowledgements

This second scholarly book as an integral part of my ongoing Ph.D. research is the fruit of rich learning experiences and enduring intellectual pursuits as part of my academic journey in Sweden and Norway. I am more indebted than I can possibly acknowledge to the people that have contributed directly, indirectly, or unknowingly to my intellectual development and knowledge enrichment. Also, I am greatly thankful to those who have supported me throughout my academic journey, encouraged me to pursue the path of 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 to this book.

I am deeply grateful to my main supervisor, Professor and Head of the Department of Computer Science John Krogstie, for giving me the opportunity to carry out my Ph.D. research in the area of data-driven smart sustainable cities of the future, allowing me to choose the topic that I am truly passionate about, and providing me with support through various means.

I also owe a great deal of gratitude to the administrative and technical staff at the Department of Computer Science for their constant support and immense help. They have contributed tangibly to providing a working environment conducive to knowledge production and intellectual advancement. The atmosphere or vibe at NTNU, coupled with flexible working hours, has been instrumental in boosting my academic productivity and performance.

Finally, and most importantly, I would like to express my deepest gratitude and appreciation to my dearest sister Amina for her wholehearted love and immeasurable moral support. I owe my life to her for the sacrifice she has made for me and for her willingness and determination to sacrifice a lot more so that I can continue to thrive in my academic endeavors and to nourish my passion for the pursuit of knowledge. Thank you for always being there beside me through thick and thin. You have long been a constantly restorative counterbalance to my life. You have made this piece of work possible and this intellectual journey delightful in more ways than one. Nothing compares to the bliss of having a sister like you.

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About the Author

Simon Elias Bibri is a Ph.D. scholar in the area of data-driven smart sustainable cities of the future and Assistant Professor at the Norwegian University of Science and Technology (NTNU), Department of Computer Science and Department of Urban Planning and Design, Trondheim, Norway. His true passion for academic and lifelong learning, coupled with his natural thirst for interdisciplinary and transdisciplinary knowledge, has led him to wittingly pursue an unusual academic journey by embarking on studying a diverse range of subject areas—at the intersection of computer science, data science, environmental science, and the social and human sciences. His intellectual pursuits and endeavors have resulted in an educational background encompassing knowledge from, and meta-knowledge about, different academic and scientific disciplines. He holds the following degrees:

1. Bachelor of Science in computer engineering with a major in software development and computer networks
2. Master of Science-research focused-in computer science with a major in Ambient Intelligence
3. Master of Science in computer science with a major in informatics
4. Master of Science in computer and systems sciences with a major in decision support and risk analysis
5. Master of Science in entrepreneurship and innovation with a major in new venture creation
6. Master of Science in strategic leadership toward sustainability
7. Master of Science in sustainable urban development
8. Master of Science in environmental science with a major in ecotechnology and sustainable development
9. Master of Social Science with a major in business administration (MBA)
10. Master of Arts in communication and media for social change
11. Postgraduate degree (one year of Master courses) in management and economics
12. Ph.D. in computer science and urban planning with a major in data-driven smart sustainable cities of the future

Bibri has earned all his Master's degrees from different Swedish universities, namely Lund University, West University, Blekinge Institute of Technology, Malmö University, Stockholm University, and Mid-Sweden University.

Before embarking on his long academic journey, Bibri had served as a sustainability and ICT strategist, business engineer, project manager, researcher, and consultant. Over the past years and in parallel with his academic studies, he has been involved in a number of research and consulting projects pertaining to smart sustainable cities, smart cities, sustainable cities, environmental engineering, green innovation, sustainable business model innovation, and green ICT strategies.

Bibri's current research interests include smart sustainable cities, sustainable cities, urban science, sustainability science, data-intensive science, data-driven and scientific urbanism, as well as big data computing and its core enabling and driving technologies, namely sensor

technologies, data processing platforms, big data applications, cloud and fog computing infrastructures, and wireless communication networks.

Bibri has a genuine interest in interdisciplinary and transdisciplinary research. Given his multidisciplinary academic background, his general research interests fall within the following areas:

- ICT of ubiquitous computing (i.e., Ambient Intelligence, the IoT, and Sentient Computing)
- Big data analytics and context-aware computing
- Data-driven smart sustainable urbanism
- Sustainable cities (e.g., compact city, eco-city, sustainable urbanism, green urbanism, etc.)
- Smart cities (e.g., real-time city, data-driven city, ambient city, ubiquitous city, sentient city, etc.)
- Sustainability transitions and socio-technical shifts
- Environmental innovations
- Philosophy and sociology of science
- Social shaping of science-based technology
- Technological innovation systems
- Sustainable business models innovation
- Technology, innovation, and environmental policies

Bibri has authored four academic books whose titles are as follows:

1. The Human Face of Ambient Intelligence: Cognitive, Emotional, Affective, Behavioral and Conversational Aspects (525 pages), Springer, 07/2015.
2. The Shaping of Ambient Intelligence and the Internet of Things: Historico-epistemic, Socio-cultural, 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 (660 pages), Springer, 03/2018.
4. Big Data Science and Analytics for Smart Sustainable Urbanism: Unprecedented Paradigmatic Shifts and Practical Advancements (505 pages), Springer, 05/2019.

1 The Evolving Data-Driven Approach to Smart Sustainable Urbanism for Tackling the Conundrums of Sustainability and Urbanization

Abstract

Opening the book as a scene-setting chapter, this chapter covers introduction and background as well as the aim, structure and content, and organization and design purposes of the book. The main topics, concepts and theories, research issues, knowledge gaps, opportunities, and prospects pointing to a need for elaboration or investigation in relevance to the focus and scope of the book are introduced in this chapter and then will be developed further or addressed and discussed in more details in the subsequent chapters as part of the systematic exploration of the field of smart sustainable/sustainable smart urbanism and the examination of the unprecedented paradigmatic shifts and practical advances it is undergoing in light of big data science and analytics and the underlying advanced technologies.

Keywords

Smart sustainable/sustainable smart urbanism • Smart sustainable/sustainable smart cities • ICT • Big data computing/analytics • Sustainability • Sustainable development • Urbanization

1 Introduction and Background

Smart sustainable/sustainable smart cities as a defining context of ICT for sustainability and urbanization have recently become the leading global paradigm of urbanism (urban planning and development). With this leading position, they are increasingly gaining traction and prevalence worldwide as a promising response to the mounting challenges of sustainability and the potential effects of urbanization. The rapidly unfolding body of work, the countless research endeavors going on, and the multitudinous unexplored opportunities within the domain of smart sustainable/sustainable smart urbanism reflect the characteristic spirit and prevailing tendency of the ICT–sustainability–urbanization era as manifested in its aspirations for increasingly directing the advances in ICT of pervasive computing toward addressing and overcoming the challenges of sustainability and containing the potential effects of urbanization within the ambit of smart sustainable/sustainable smart cities. Furthermore, the subject of 'smart sustainable/sustainable smart cities' is endlessly enticing and magnetizing, whether from an intellectual or practical perspectives, as there are numerous actors involved in the academic and practical aspects of the endeavor, including engineers and architects, green and energy efficiency technologists, built and natural environment specialists, environmental and social scientists, ICT experts, computer and data scientists, and applied urban scientists. All these actors are undertaking research and developing strategies, approaches, and programs to tackle the challenging elements of smart sustainable/sustainable smart urbanism. This adds to the work of policymakers and political decision-makers in terms of formulating and implementing regulatory policies and devising and applying political mechanisms and governance arrangements to promote and spur innovation and monitor and maintain progress within such urbanism.

Indeed, modern cities have a central and defining role in strategic sustainable development; therefore, they have gained a central position in operationalizing and applying it. This is clearly reflected in the Sustainable Development Goals (SGDs) of the United Nations' 2030 Agenda for Sustainable Development, which entails, among other things, making cities more sustainable, resilient, and safe (UN 2015a), as well as well documented by European Commission (2011). This is anchored in the recognition that cities as the engines of, and the hubs of innovation that drive economic development are the world's

S. E. Bibri, *Big Data Science and Analytics for Smart Sustainable Urbanism*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-030-17312-8_1

major consumers of energy resources and significant contributors to GHG emissions. It is estimated that they consume about 67% of the global energy demand and generate up to 70% of the harmful GHG emissions. Accordingly, they represent the key generators of environmental pollutants and the main hot spots of vulnerability to climatic hazards and related upheavals, in addition to social inequality, disparity, vulnerability, and insecurity (Bibri 2018a, 2019a). In view of that, they are seen as the most important arena for instigating major sustainability transitions and thus making a significant contribution to sustainable urban transformations by linking the agenda of sustainable development with that of ICT of pervasive computing research and development. In addition, they constitute the key sites of economic, environmental, and social dynamism and innovation, thereby holding great potential for bringing about societal transformation and cultural enhancement (Bibri 2018a, c). Their prominence in this regard emanates from that they encompass different, yet related, innovation systems, including national, regional, sectoral, technological, and quadruple helix of university–industry–government–citizen relations. As such, they provide ideal testing grounds and operating environments for innovative ICT solutions pertaining to diverse urban systems and domains in the context of sustainability. In this respect, the United Nations's 2030 Agenda regards ICT as a means to promote socio-economic development and protect the environment, increase resource efficiency, achieve human progress and knowledge in societies, upgrade legacy infrastructure, and retrofit industries based on sustainable design principles (UN 2015a, b). Hence, the multifaceted potential of the smart city approach as enabled by ICT has been under investigation by the UN (2015c) through their study on 'Big Data and the 2030 Agenda for Sustainable Development'. In particular, there is an urgent need for developing and applying innovative solutions and sophisticated methods to overcome the environmental challenges of urbanization (UN 2016) and sustainability (Batty et al. 2012; Bibri 2018a, 2019a; Bibri and Krogstie 2017b). Undoubtedly, the main strength of the big data technology is the high influence; it will have on many facets of smart sustainable/sustainable smart cities and their citizens' lives (see, e.g., Al Nuaimi et al. 2015; Angelidou et al. 2017; Batty et al. 2012; Bettencourt 2014; Bibri 2018a, b, 2019a; Bibri and Krogstie 2017a, b; Pantelis and Aija 2013; Townsend 2013). Manifestly, the unfolding and soaring urban data deluge with its extensive and new sources hides in itself the answers to the most challenging analytical questions as well as the solutions to the most complex challenges pertaining to urbanization and sustainability, in addition to playing, a key role in understanding urban constituents as data agents. Likewise, sustainable urban planning and development represent a process of change that promotes the health of citizens, communities, and natural ecosystems and fosters economic development while conserving resources in the face of urbanization. The way forward for cities to better cope with the restructuring and changing conditions is to adopt the long-term approach that emphasizes sustainability (Bulkeley and Betsill 2005). While the concept of sustainable development has enhanced cities with the planning principles and ecological design of sustainability, smart development as being predominately driven by big data computing is striving to enhance sustainable cities by smartening up their sustainability performance. It has become of high pertinence and importance to augment sustainable cities with big data technology and its novel applications so as to boost this performance (Bibri and Krogstie 2017b). Overall, modern cities are well positioned to evolve in ways that address and overcome environmental concerns and respond to socio-economic needs in an increasingly technologized, computerized, and urbanized world. They are the incubators, generators, and transmitters of creative ideas and innovative solutions for solving many complex problems and pressing issues (Bibri and Krogstie 2017a).

The world is fast moving to cities and for the long term as manifested in the rapid and continuous urbanization taking place since the beginning of the last century. With more than half of the world's population living in urban areas, and by 2050 more than two-thirds (66%) is expected to be urbanized (UN 2015d), coupled with the rising concerns over the environment and social inequality and vulnerability, it is time to turn our attention to cities and to unlock their creativity and innovation potential in order to tackle these enormous challenges. Unprecedented in their magnitude and influence in history, the spread of urbanization and the rise of ICT are among the most important global shifts at play across the world today and will undoubtedly change urbanism in a drastic and irreversible way. As widely estimated, the urban world will become largely technologized, computerized, and urbanized within just a few decades, and ICT as an enabling, integrative, and constitutive technology of the twenty-first century will accordingly be instrumental, if not determining, in solving many of the conundrums posed, the issues raised, and the challenges presented by urbanization (Bibri 2019a). It is therefore of strategic value to start directing the use of emerging ICT into understanding and proactively mitigating the potential effects of urbanization, with the primary aim of tackling the many intractable and wicked problems involved in urban operational functioning, management, planning, and development, especially in the context of sustainability, which is another macro-shift at play across the world today. Indeed, the anticipated urbanization of the world poses significant and unprecedented challenges associated with sustainability (e.g., David 2017; Han et al. 2016; Estevez et al. 2016) due to the issues engendered by urban growth in terms of resource depletion, environmental degradation, intensive energy usage, air and water pollution, toxic waste disposal, endemic traffic congestion, ineffective decision-making processes, inefficient

planning systems, mismanagement of urban infrastructures and facilities, poor housing and working conditions, public health and safety decrease, social vulnerability and inequality, and so on (Bibri 2018a), in spite of urbanization epitomizing an emblem of social evolution. These accordingly affect the quality of life and well-being of citizens as well as the efficiency of urban operations and functions (Degbelo et al. 2016). In short, the multidimensional effects of unsustainability in modern and future cities are most likely to exacerbate with urbanization (Bibri 2018a). Indeed, urbanization as a dynamic clustering of people, buildings, infrastructures, and resources strains and puts pressure on the limited urban and natural resources and affects the resilience to the growing demands on them, and urban functioning, management, planning, and governance face ever-mounting challenges. The underlying argument is that urban growth will jeopardize the sustainability of cities as to its environmental, economic, and social dimensions. Again, to disentangle this kind of intractable problems requires evidently major shifts in urban thinking and planning—i.e., newfangled ways founded on more innovative solutions and sophisticated approaches with respect to how cities can be understood, operated, managed, planned, designed, developed, and governed (Bibri 2018a; Bibri and Krogstie 2017a). In this regard, advanced ICT can provide integrated information intelligence for enhancing urban functioning, socio-economic forecasting, and policy design on the basis of participatory, poly-centric, and digital models and processes of governance.

Therefore, ICT has come to the fore and become of crucial importance for winning the battle of sustainability and containing the potential effects of urbanization. ICT becoming part of mainstream debate in this regard stems from the increasing ubiquity presence of, and new discoveries in, computing, coupled with the massive use of its technological applications across various urban systems and domains. In fact, advanced technologies and novel approaches are now more needed than ever to address and overcome the challenges and issues facing modern and future cities. This pertains to the way such cities should be monitored, understood, analyzed, and, hence, operated, managed, organized, and planned to improve, advance, and maintain their contribution to the goals of sustainable development. It is therefore an unsurpassed opportunity to use advanced ICT to rise to the challenges of sustainability and urbanization in new ways and to resolve the many intractable and wicked problems involved in urban management, planning, and development. There is an increasing recognition that emerging and future ICT constitutes a promising response to the challenges of urban sustainability due to its tremendous, yet untapped, potential to catalyze and boost sustainable development processes. Many urban development approaches reference the role of ICT in achieving the goals of sustainable development (Bibri 2019a). As pointed out by Bibri (2019a), the use of advanced ICT in both sustainable cities and smart cities constitutes an effective approach to decoupling the health of the city and the quality of life of citizens from the energy and material consumption and concomitant environmental risks associated with urban operations, functions, services, designs, strategies, and policies. In this respect, it is important to consider urgent urban needs, emerging computing and societal trends, urban readiness for the upcoming change, available resources, and technological capabilities, cutting-edge innovations, and smart initiatives and solutions directed for sustainable transformations. These entail developing visionary approaches, comprehensive frameworks, and roadmaps for organizing and launching concrete projects, supported by long-term strategic and operational objectives and immediate policy measures for guiding and sustaining the needed transformative processes.

Against the backdrop of the unprecedented rate of urbanization and the complex problems of sustainability, an array of alternative ways of understanding, operating, managing, planning, designing, developing, and governing cities based on advanced ICT is materializing and evolving in terms of how smart cities can transition toward the needed sustainable development and sustainable cities can enhance their sustainability performance. This can be attained through adopting a set of integrated frameworks, strategies, and policies to foster advancement and innovation in urban systems and domains in line with the goals of sustainability. An increasing urgency to find and apply innovative solutions is motivated by the increasing urban growth and the diffusion of sustainable development in terms of seeking out ways to circumvent the associated effects and challenges, respectively. In particular, Townsend (2013) portrays urban growth and ICT development as a form of symbiosis. This entails an interaction that is of advantage to, or a mutually beneficial relationship between, ICT and urbanization (Bibri and Krogstie 2017a). One way of looking at this form of tie-in is that urbanization can open entirely new windows of opportunity, or simply provide a fertile environment, for cities to act as vibrant hubs of technological innovations in a bid to solve a wide variety of environmental, social, and economic problems and challenges, thereby containing the potential effects of urbanization. Indeed, a large number and variety of sophisticated technologies and their novel applications, especially those enabled by big data computing, are being developed and applied in response to the need for finding more effective ways to deal with the complexity of the knowledge necessary for understanding, operating, managing, and planning modern cities as complex systems and dynamically changing environments. This entails developing and implementing novel decision-making processes based on new urban intelligence functions and powerful new forms of simulation models and optimization and prediction methods, which are enabled by big data analytics. Modern cities must take greater advantages of emerging and future technologies to be able to move with the times as to handling their

operations, functions, designs, services, strategies, and policies. We are at a critical point in this evolution as new technological and societal forces are merging to create new approaches to smart sustainable/sustainable smart urbanism. While the two main urbanism approaches: sustainable cities and smart cities, as a set of practices have been evolving for quite some time: since the diffusion of sustainable development around the late 1980s and the prevalence of ICT around the mid-1990s, what is presently new is that the emerging urban initiatives and endeavors are rather shifting from merely focusing on the application of sustainability knowledge to the operational functioning, planning, design, and development of cities or the development and deployment of smart technologies to optimize these urbanism practices in cities to connecting the sustainable city and smart city as both landscapes and approaches, in addition to creating integrated frameworks for mitigating the potential effects of urbanization. In more detail, 'since the late 1980s, the discourse on sustainable cities has focused on the environmental, social, and economic sustainability of cities, and since the 1990s, the focus has turned to the discourse on smart cities emphasizing ICT as a lens to see the future form of urbanism. ICT has since gained recognition that it can contribute to transforming cities into spaces that can adapt to environmental, societal, and economic shocks. Compared to smart cities and sustainable cities, which have been around for quite sometime, smart sustainable/sustainable smart cities have come to light over the past few years … While there is a growing interest in this flourishing, interdisciplinary field of research, the academic discourse on smart sustainable urban planning and development within the relevant literature is still scant-yet rapidly burgeoning … The case is evidently different from smart cities and sustainable cities as urban planning and development approaches, which have witnessed a proliferation of academic publications and thus varied emphases of research and a large body of successful practices. However, the speed at which the field of smart sustainable/sustainable smart cities is gaining momentum and attracting attention gives a clear indication of its developmental path, blossoming nature, and future direction. In fact, this field of research comes as a natural pursuit within urban planning and development in light of the unsolved issues and intellectual challenges pertaining to existing sustainable city models in terms of their contribution to the goals of sustainable development, as well as in terms of the deficiencies and conundrums associated with existing smart city approaches in terms of their incorporation of the goals of sustainable development' (Bibri 2018a, p. 7) and their risks to environmental and social sustainability (Bibri 2019a).

In light of the above, a recent research wave has started to focus on smartening up sustainable cities in ways that can improve, advance, and maintain their contribution to the goals of sustainable development, as well as on incorporating these goals into smart cities in a bid to enhance their sustainability performance (Bibri 2018a, b, c, 2019a, b). Explicitly, this wave centers around amalgamating the landscapes of, and the approaches to, sustainable cities and smart cities in a variety of ways in the hopes of reaping the numerous benefits of sustainability through enhancing and optimizing urban operational functioning, management, planning, and governance in line with the goals of sustainable development under what is labeled 'smart sustainable cities' or 'sustainable smart cities', respectively. These two integrated approaches tend to take multiple forms in terms of combining the strengths of sustainable cities and smart cities based on how the concept of smart sustainable/sustainable smart cities can be conceptualized and operationalized. As a corollary of this, there is a multitudinous array of unexplored opportunities toward new approaches to smart sustainable/sustainable smart urbanism in order to mitigate or overcome the extreme fragmentation and weak connection between the landscapes of, and the approaches to, sustainable cities and smart cities, respectively. In view of that, there has recently been a conscious push for sustainable cities and smart cities across the globe to be smarter and thus more sustainable by particularly implementing big data technology and its novel applications in the hopes of reaching the optimal and required levels of sustainability, respectively. This is due to the kind of well-informed decision-making and enhanced insights enabled by big data analytics in the form of applied intelligence and planning functions. As an advanced form of ICT of pervasive computing, big data technology and its applications are increasingly becoming of crucial importance to new approaches to smart sustainable/sustainable smart urban planning and development, gaining traction and foothold among urban scholars, scientists, practitioners, and policymakers over the past few years (Bibri 2018a, 2019a). Urban big data computing and the underpinning technologies have become essential to the operational functioning of cities, and consequently, urban planning, development, governance, and services are becoming highly responsive to a form of data-driven urbanism (Kitchin 2014, 2015, 2016), especially within the sphere of smart sustainable/sustainable smart cities (Bibri 2018a, 2019a, b).

One of the salient driving factors for urbanism embracing the wave of data-driven smartness and sustainability as combined lies in the fertile environment and immense opportunity being created through the utilization of the innovative solutions and sophisticated approaches (i.e., intelligence and planning functions, simulation models, prediction and optimization methods, intelligent decision support systems, etc.). These are increasingly enabled and afforded by big data technologies for data acquisition, storage, management, processing, and analysis that are primarily intended and applied for supporting the goals of sustainable development and thus advancing sustainability (Bibri 2018a). This is manifested in the rapid evolvement of smart sustainable/sustainable smart cities as a new approach to and a new leading paradigm of urbanism into becoming more and

more computationally augmented and digitally instrumented and hence technologically advanced and data-analytically driven in relation to operational functioning, planning, design, and development practices with respect to sustainability and the integration of its dimensions. In several information societies, national urban projects are investing heavily in, and focusing on strengthening the role of, big data technologies in smart sustainable/sustainable smart urbanism (Bibri 2018a). If this approach is understood as what smart cities are doing to incorporate the goals of sustainable development, on the one hand, and sustainable cities are doing to smarten up their sustainability performance and how they do it, on the other hand, then the scholarly enterprise of big data analytics and the role of its uses in catalyzing and boosting the process of sustainable development and, thus, in facilitating the contribution of both smart cities and sustainable cities to those goals is most likely to represent an important changing dynamic in the transition toward smart sustainable/sustainable smart cities based on data-driven urbanism. In a nutshell, data-driven approach is of paramount importance to smart sustainable/sustainable smart urbanism. Indeed, aligning the functioning and performance of urban systems as well as the coordination and integration of urban domains with the agenda of sustainable development and the vision of sustainability require sophisticated technologies and profound data analytics capabilities to leverage the underlying complex interdisciplinary and transdisciplinary knowledge in the enhancement of decision-making in urban planning, design, and development. Currently, smart sustainable/sustainable smart urbanism as an approach entails harnessing ideas about how advanced big data technologies can optimize efficiency, boost resilience, improve equity, and enhance the quality of life by developing and implementing novel solutions and sophisticated methods for addressing and overcoming environmental and socio-economic problems on the basis of the automated extraction of useful knowledge and valuable insights from the unfolding and soaring deluge of urban data for well-informed, fact-based, strategic decision-making in the realm of smart sustainable/sustainable smart cities. In short, the value of big data computing lies in finding more effective ways of how data can be applied and how new data-driven innovations can be facilitated and diffused throughout the systems and domains of such cities for instigating and stimulating the sought-after, drastic transformations. One key facet of such transformations is how to improve the different aspects of sustainability by translating it into the built, spatial, infrastructural, operational, functional, and serviceable forms of such cities.

On the whole, the phenomenon of smart sustainable/sustainable smart cities has emerged as a result of an amalgam of dominating and long-lasting trends, including global shifts (urbanization, sustainability, and ICT), intellectual discourses (e.g., sustainable development, sustainable urbanism, and smart urbanism), academic discourses (e.g., sustainable cities, smart cities, and smarter cities), computing paradigms (ubiquitous computing, big data computing, and the IoT), and technological innovations (e.g., big data analytics, big data technologies, big data applications, and fog/edge computing models). The dynamic interplay between these varied forms of trends, which will undoubtedly continue to evolve simultaneously and affect one another in a mutual process for many years yet to come, is the backcloth against which many recent innovations and transition endeavors or undertakings have emerged and materialized, and thus, countless opportunities have been created and exploited within the sphere of data-driven smart sustainable urbanism within both ecologically and technologically advanced nations. In particular, as a paradigmatic shift in societal thinking of a kind that is unprecedented, sustainability has been determining in instigating and engendering drastic changes in the core practices, primary operations, and central institutions of ecologically advanced nations in response to the goals and challenges of sustainable development over the past three decades or so (Bibri 2018a). Many technologically advanced nations have also started to exhibit shifting patterns as to responding to these goals and challenges, as well as in response to the global calls for tackling the pressing issues of urbanization by developing and implementing the most innovative solutions and sophisticated approaches being offered by big data computing and the underpinning technologies. This is increasingly being fueled by the recent advances in ICT and its ever-growing embeddedness into the very fabric of contemporary cities. Indeed, in both smart sustainable cities and sustainable smart cities, urban systems are becoming complexly and intricately interconnected and integrated and urban domains increasingly heavily favorably networked and coordinated, thereby giving rise to new urban environments that must rely on the use of more sophisticated technologies to realize their full potential as to responding to the environmental and socio-economic challenges of sustainability in an increasingly urbanized world (Bibri 2018a).

2 The Aim of the Book

Integrating and fusing theoretical and practical perspectives from a number of city-related disciplinary fields and combining them with the recent computational innovations and technological advancements, this book explores the field of smart sustainable urbanism and the unprecedented paradigmatic shifts and practical advances it is undergoing in light of big data science and analytics, as well as highlights and discusses how these shifts and advances intertwine with and affect one

another. This exploration also includes a comprehensive, state-of-the-art review of the field of data-driven smart sustainable urbanism in terms of data-driven cities, smart cities, smarter cities, sustainable cities, and smart sustainable/sustainable smart cities approaches, as well as big data analytics and application.

Moreover, this book involves the various strands of urbanism: operational functioning, planning, design, and development, and how these interrelate synergistically with respect to sustainability and related big data technologies and their novel applications and sophisticated approaches in the ambit of smart sustainable cities. Indeed, at the core of smart sustainable urbanism is the synergy between urban operational functioning, planning, design, and development as regards their interaction or cooperation to produce a combined effect greater than the sum of their separate effects. This entails using big data computing and the underpinning technologies as an enabler for such synergy and a determinant of its outcomes.

In light of the above, this book brings together the sciences underlying smart sustainable urbanism, which underpin the understanding, development, and application of technologies, to improve, advance, and maintain the contribution of both sustainable cities and smart cities to sustainability over the long run. In doing so, it highlights the need to consider the science and technology for environmental and social benefits in the context of smart sustainable/sustainable smart cities, as well as the environmental and social evidence for the uptake and success of the technologies underlying big data science and analytics. In a nutshell, this book brings together scholars, researchers, scientists, and practitioners to promote collaborations, enhance practices, discuss new opportunities, analyze emerging trends, and investigate advanced analytics and related frameworks along with their applications to real-life situations pertaining to sustainability and urbanization.

3 The Structure and Content of the Book

The book is divided into (11) chapters. Opening the book as a scene-setting chapter, this chapter covers introduction and background as well as the aim, structure and content, and organization and design purposes of the book. The main topics, concepts and theories, research issues, knowledge gaps, opportunities, and prospects pointing to a need for elaboration or investigation in relevance to the focus and scope of the book are introduced in this chapter and then will be developed further or addressed and discussed in more details in the subsequent chapters as part of the systematic exploration of the field of smart sustainable/sustainable smart urbanism and the examination of the unprecedented paradigmatic shifts and practical advances it is undergoing in light of big data science and analytics and the underlying advanced technologies.

Chapter 2 provides a comprehensive, state-of-the-art review of smart sustainable/sustainable smart cities as a leading paradigm of urbanism in terms of the underlying foundational components and assumptions, research status, issues and debates, research opportunities and challenges, future practices and horizons, and technological trends and developments. As to the findings, this chapter shows that smart sustainable urbanism involves numerous issues that are of unsolved, largely ignored, or underexplored from an applied theoretical perspective. And a large part of research in this area focuses on exploiting the potentials of big data technologies and their novel applications as an effective way to mitigate or overcome the issue of sustainable cities and smart cities being extremely fragmented as landscapes and weakly connected as approaches. The comprehensive overview of and critique on existing work on smart sustainable urbanism provides a valuable reference for researchers and practitioners in related research communities, and the necessary material to inform these communities of the latest developments in the area of smart sustainable urban planning and development. The outcome of this topical review will help strategic city stakeholders understand what they can do more to advance sustainability based on big data technology and its novel applications and also give policymakers an opportunity to identify areas for further improvement while leveraging areas of strength with regard to the future form of sustainable smart urbanism in the era of big data.

Chapter 3 endeavors to systematize the complex field of smart sustainable/sustainable smart urbanism by identifying, distilling, mixing, fusing, and thematically analytically organizing the core dimensions of a foundational approach consisting of a set of relevant concepts, theories, discourses, and academic and scientific disciplines that underpin this field for research and practice. The primary intention of setting such approach is to conceptually and analytically relate urban planning and development, sustainable development, and urban science while emphasizing why and the extent to which sustainability and big data computing have particularly become influential in urbanism in modern society. Being interdisciplinary and transdisciplinary in nature, such approach is meant to further highlight that this scholarly character epitomizes the orientation and essence of the research field of smart sustainable/sustainable smart urbanism in terms of its pursuit and practice. Moreover, its value lies in fulfilling one primary purpose: to explain the nature, meaning, implications, and challenges pertaining to the multifaceted phenomenon of smart sustainable/sustainable smart urbanism. This chapter provides an important lens through which to understand a set of theories that is of high integration, fusion, applicability, and influence potential in relation to smart sustainable/sustainable smart urbanism. In this subject, in particular, theories from academic

and scientific disciplines constitute a foundation for action—data-driven smart sustainable urbanism and related urban big data development as informed by data science practiced within the fields of urban science and urban informatics as well as sustainability science and sustainable development.

Chapter 4 intends to provide a detailed qualitative analysis of the key forms of trends shaping and driving the emergence, materialization, and evolvement of the phenomenon of smart sustainable cities as a leading paradigm of urbanism, as well as to identify the relevant expected developments related to smart sustainable urbanism. It is more likely that these forms of trends reflect a congeries of long-lasting forces behind the continuation of smart sustainable cities as a set of multiple approaches to, and multiple pathways to achieving, smart sustainable urbanism. As part of the futures studies related to smart sustainable city planning and development using a backcasting methodology, both the trends and expected developments are key ingredients of, and crucial inputs for, analyzing different alternative scenarios for the future or long-term visions pertaining to desirable sustainable futures in terms of their opportunities, potentials, environmental and social benefits, and other effects. This study serves to provide a necessary material for scholars, researchers, and academics, as well as other futurists, who are in the process of conducting or planning to carry out, futures research projects or scholarly backcasting endeavors related to the field of smart sustainable urbanism.

Chapter 5 has a threefold aim. First, it examines how data-driven smart sustainable cities are being instrumented, datafied, and computerized so as to improve, advance, and maintain their contribution to the goals of sustainable development through enhanced practices. Second, it highlights and substantiates the real potential of big data technology for enabling such contribution by identifying, synthesizing, distilling, and enumerating the key practical and analytical applications of this advanced technology in relation to multiple urban systems and domains with respect to operations, functions, services, designs, strategies, and policies. Third, it proposes, illustrates, and describes a novel architecture and typology of data-driven smart sustainable cities. This chapter intervenes in the existing scholarly conversation by calling attention to a relevant object of study that previous scholarship has neglected and whose significance for the field of urbanism is well elucidated, as well as by bringing new insights into and informing the ongoing debate on smart sustainable urbanism in light of big data science and analytics. This work serves to bring data-analytic thinking and practice to smart sustainable urbanism and seeks to promote and mainstream its adoption, in addition to drawing special attention to the crucial role and enormous benefits of big data technology and its novel applications as to transforming the future form of such urbanism.

Chapter 6 examines the unprecedented paradigmatic, scientific, scholarly, epistemic, and discursive shifts the field of smart sustainable urbanism is undergoing in light of big data science and analytics and the underlying advanced technologies, as well as discusses how these shifts intertwine with and affect one another, and their sociocultural specificity and historical situatedness. I argue that data–intensive science as a new paradigmatic or epistemological shift is fundamentally changing the scientific and practical foundations of urban sustainability. In specific terms, the new urban science—as underpinned by sustainability science—is increasingly making cities more sustainable, resilient, efficient, livable, and equitable by rendering them more measurable, knowable, and tractable in terms of their operational functioning, management, planning, design, and development.

Chapter 7 provides a comprehensive, state-of-the-art review and synthesis of the field of smart and smarter cities in relation to sustainability and related big data applications in terms of the underlying foundations and assumptions, research issues and debates, opportunities and benefits, technological developments, emerging trends, future practices, and challenges and open issues. This study shows that smart and smarter cities are associated with misunderstanding and deficiencies as regards their incorporation of, and contribution to, sustainability, respectively. Nevertheless, as also revealed by this study, tremendous opportunities are available for utilizing big data applications in smart cities of the future or smarter cities to improve their contribution to the goals of sustainable development through optimizing and enhancing urban operations, functions, services, designs, strategies, and policies, as well as finding answers to challenging analytical questions and advancing knowledge forms. However, just as there are immense opportunities ahead to embrace and exploit, there are enormous challenges ahead to address and overcome in order to achieve a successful implementation of big data applications in such cities. These findings will help strategic city stakeholders understand what they can do more to advance sustainability based on big data applications and also give policymakers an opportunity to identify areas for further improvement while leveraging areas of strength with regard to the future form of sustainable smart urban development.

Chapter 8 has a twofold aim. First, it provides a comprehensive, state-of-the-art review of the domain of sustainable urbanism, with a focus on compact cities and eco-cities as models of sustainable urban forms and thus instances of sustainable cities, in terms of research issues and debates, knowledge gaps, challenges, opportunities, benefits, and emerging practices. Second, it highlights and substantiates the real, yet untapped, potential of big data technology and its novel applications for advancing sustainable cities. In so doing, it identifies, synthesizes, distills, and enumerates the key practical and analytical applications of big data technology in relation to multiple urban domains. This study shows that sustainable

urban forms involve limitations, inadequacies, difficulties, fallacies, and uncertainties in the context of sustainability, in spite of what has been realized over the past three decades or so within sustainable urbanism. Nevertheless, as also revealed by this study, tremendous opportunities are available for exploiting big data technology and its novel applications to smarten up sustainable urban forms in ways that can improve, advance, and sustain their contribution to the goals of sustainable development by optimizing and enhancing their operations, functions, services, designs, strategies, and policies across multiple urban domains, as well as by finding answers to challenging analytical questions and transforming the way knowledge can be developed and applied. These findings will help strategic stakeholders understand what they can do more to advance sustainable urbanism based on big data computing and also give policymakers an opportunity to identify areas for further improvement while leveraging areas of strength with regard to the future form of smart sustainable urbanism.

Chapter 9 develops, illustrates, and discusses a systematic framework for city analytics and 'big data' studies in relation to the domain of smart sustainable/sustainable smart urbanism based on cross-industry standard process for data mining. This endeavor is in response to the emerging paradigm of big data computing and the increasing role of underpinning technologies in operating, organizing, planning, and designing smart sustainable cities as a leading paradigm of urbanism. The intention is to utilize and apply well-informed, knowledge-driven decision-making and enhanced insights to improve and optimize urban operations, functions, services, designs, strategies, and policies in line with the long-term goals of sustainability. I argue that there is tremendous potential for advancing smart sustainable urbanism or transforming the knowledge of smart sustainable cities through creating a data deluge that can, through analytics, provide much more sophisticated, finer-grained, wider-scale, real-time understanding and control of various aspects of urbanity in the undoubtedly upcoming Exabyte/Zettabyte Age.

Chapter 10 examines and discusses the approach to data-driven smart sustainable/sustainable smart urbanism in terms of computerized decision support and making, intelligence functions, simulation models, and optimization and prediction methods. It also documents and highlights the potential of the integration of these advanced technologies for facilitating the synergy between the operational functioning, planning, design, and development of smart sustainable/sustainable smart cities for the primary purpose of improving, advancing, and maintaining their contribution to the goals of sustainable development. I conclude that the upcoming developments and innovations in big data computing and the underpinning technologies, coupled with the unfolding and soaring deluge of urban data, hold great potential for enhancing and advancing the different practices of smart sustainable/sustainable smart urbanism. This work serves to contribute to bringing data-analytic thinking and practice to smart sustainable/sustainable smart urbanism, as well as seeks to promote and mainstream its adoption across the urban world, in addition to drawing special attention to the crucial role and enormous benefits of the emerging paradigm of big data computing as to transforming the future form of such urbanism.

Chapter 11 is an integral part of an ongoing futures study whose aim is to analyze, investigate, and develop a novel model for smart sustainable city of the future using backcasting as a scholarly and planning methodology. In doing so, it endeavors to integrate the physical landscape of sustainable cities with the informational landscape of smart cities at the technical level, as well as to merge the two strategies on several scales, all in the context of sustainability. This chapter is concerned with Step 3 of the backcasting approach being used to achieve the overall aim of the futures study. In this respect, it aims to report the outcome of Step 3 by answering 6 guiding questions. Visionary images of a long-term future can stimulate an accelerated movement toward achieving the long-term goals of sustainability. The proposed model is the first of its kind and thus has not been, to the best of one's knowledge, produced, nor is it being currently investigated, elsewhere.

Chapters 2–11 have a standardized scholarly research structure, which makes them easy to navigate and read. Specifically, these chapters are presented and organized in the form of journal articles consisting of abstract, introduction, analysis, and discussion and conclusion. Some of them include research approaches as well. As to the conceptual, theoretical, and disciplinary background underpinning these chapters, it is covered separately in Chap. 3.

By and large, this book is about data-driven smart sustainable/sustainable smart urbanism in the sense of exploiting and leveraging the unfolding and soaring deluge of urban data through advanced data analytics techniques to extract useful knowledge and valuable insights into the form of applied intelligence intended for enhancing decision-making pertaining to urban operational functioning, management, planning, development, and governance in the context of sustainability. As the massive collection of data has spread through just about every domain of both sustainable cities and smart cities, so have the opportunities for big data science and analytics as related to smart sustainable cities and sustainable smart cities. Underlying the extensive body of big data analytics is a much smaller set of fundamental concepts comprising data science as practiced within the field of urban science in relevance to the topic of this book. These concepts are general and encapsulate much of the essence of big data analytics in relation to urban analytics and big data studies as underpinning urban functions, operations, services, designs, strategies, and policies. Success in today's data-driven smart sustainable/sustainable smart urbanism entails the ability to think about how these fundamental concepts apply to particular sustainability problems in short, to think data-analytically about such problems. The premise is that big data should be thought of as a strategic asset in

the realm of smart sustainable/sustainable smart cities, a direction of thinking that brings the fundamental question of how much such cities should invest in big data analytics. Thus, an understanding of these fundamental concepts is especially important for anyone using such analytics in any urban domain that is associated with sustainability. There is growing evidence that data-driven decision-making and related advanced technologies can substantially improve sustainability performance through enhancing and optimizing urban operations, functions, services, designs, strategies, and policies in relation to diverse of urban domain. Furthermore, in 15 years' time, the predominant computational and analytical algorithms, data-intensive techniques, mathematical models, data processing platforms, and cloud and fog computing infrastructures as the core enabling and underpinning technologies of big data computing will most likely have advanced enough that a detailed discussion in this book would be obsolete. Whereas, the general principles are the same as they were 20 or so years ago, and will likely change little over the coming decades. Besides, there are so many books out there that cover such technologies in more detail with illustrative examples for those reader interested in exploring further the field of big data computing/analytics, whether in relation to the city or other venues.

4 The Organization and Design Purposes of the Book

This book is organized in a way to achieve two main outcomes. Firstly, it is written so that the readers can read it easily from end to end. Whether the readers read it in several sessions or go through a little every now and then, they will find it interesting to read and accessible–especially those with passionate interest in, and prior knowledge about, smart sustainable urbanism, or with deep curiosity about big data computing as a disruptive technology and its far-reaching implications for every domain of urban life. Secondly, it is written so that the readers can call upon specific parts of its content in an easy to do manner. Indeed, each of its chapters can be read on its own or in sequence. It is difficult to assign a priority rating to the chapters given that the book is intended for readers with different backgrounds and interests, but the readers will get the best out of it from reading the whole book in the order it is written so that they can gain a deep understanding of smart sustainable/sustainable smart urbanism as driven by big data science and analytics. However, if the readers are short of time and must prioritize, they can start with those chapters they find of highest relevance and importance based on their needs or interests. Therefore, as to how relevant and important the topics of the book are, the choice is yours based on your own assessment and subjective interpretation.

Overall, this book has been carefully designed to provide the tools, material, and repository required to explore the realm of smart sustainable/sustainable smart urbanism, which is an extremely complex, dynamic, and challenging area of thinking and practice. Hence, it is well worth exploring in some depth and from multiple perspectives. The best way to enable the readers to embark on such exploration is to seamlessly amalgamate multiple perspectives and to harness this amalgamation in relevance to sustainability, in a multifaceted, unified analysis, synthesis, and evaluation. Achieving this kind of amalgamation in a form of a systematic examination is the main strength and major merit of this book. And succeeding in doing so is meant to provide the readers with valuable insights into the emerging scientific and technological innovations and their anticipated role in, and their implications for, enabling smart sustainable/sustainable smart cities as a leading paradigm of urbanism and making living in them an attainable reality, as well as into the more effective ways of addressing and overcoming the challenges of sustainability in the face of urbanization. Adding to this is to offer the people of ecologically and technologically advanced nations the resources with which to evaluate the opportunities for such cities to win the battle of sustainability and tackle the pressure of urbanization in the years ahead in the upcoming age of big data. This is believed to be an important achievement in its own right and certainly makes this book a rewarding reading and learning experience for those who feel they could benefit from and deepen their understanding of the domain of smart sustainable/sustainable smart urban planning and development. I encourage the readers to make the most of this opportunity to explore smart sustainable/sustainable smart cities as an inspiring vision in the upcoming Exabyte/Zettabyte Age. While some of us might shy away from foreseeing what the future urban world will look like with the imminent advancements and disruptive innovations in big data computing and the underpinning technologies, it is certain that it will be a very different world from what has hitherto been experienced on many scales. I wish you well on the exploration journey.