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Simon Elias Bibri

Advances in the Leading Paradigms of Urbanism and their Amalgamation

Compact Cities, Eco–Cities, and Data–Driven Smart Cities

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Simon Elias Bibri
Department of Computer Science
Department of Architecture and Planning
Norwegian University of Science and Technology
Trondheim, Norway

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Preface

This timely book is concerned with the recent advances in the leading paradigms of urbanism, namely compact cities, eco-cities, and data-driven smart cities, and the evolving approach to their amalgamation under the umbrella term of smart sustainable cities of the future. Sustainable urban development is today seen as one of the keys toward unlocking the quest for a sustainable world. And the big data revolution is set to erupt in cities throughout the world, heralding an era where instrumentation, datafication, and computation are increasingly pervading the very fabric of cities and the spaces we live in thanks to the IoT. Big data and the IoT technologies are seen as powerful forces that have tremendous potential for advancing urban sustainability. Indeed, they are instigating a massive change in the way sustainable cities can tackle the kind of special conundrums, wicked problems, and significant challenges they inherently embody as complex systems. They offer a multitudinous array of innovative solutions and sophisticated approaches informed by groundbreaking research and data–driven science.

This book will elicit new insights and offer new perspectives to spark novel ways of inquiry within the domain of sustainable urbanism. The primary aim in this regard is to bring scholars and practitioners closer together from different disciplines and professional fields, or those already working on cross connections of urban sustainability, sustainability science, complexity science, urban science, data science, and computer science, to develop, concretize, and disseminate new ideas for advancing sustainable urbanism and promoting related strategies, approaches, programs, and initiatives based on sophisticated technologies and their innovative solutions. Indeed, this book is based on a uniquely holistic perspective, adopting a compelling approach to cross-disciplinary integration and fusion between diverse academic and scientific disciplines.

This seminal work provides the necessary material to inform the research communities concerned with the recent advances in sustainable urbanism with the state-of-the-art research and the latest development in this area. It also provides a valuable reference for practitioners who are seeking to contribute to, or already working with, the development and implementation of smart sustainable cities as a leading paradigm of urbanism based on big data analytics and the IoT. In this respect, the upshot of this book enables researchers to focus their work on the extreme fragmentation of and weak connection between sustainable cities and smart cities as landscapes and approaches, respectively, in terms of embracing what emerging and future ICT has to offer to advance sustainability. Practitioners can use the outcome of this book to identify common weaknesses, flaws, and difficulties within sustainable urbanism and then deal with them through devising and implementing alternative solutions on the basis of what big data analytics and the IoT have to offer as novel applications and sophisticated approaches. These pertain to new ways of optimizing and enhancing urban operational functioning, planning, design, development, and governance in response to the challenges of sustainable development.

While this book can best be seen as being aimed at those with a background in both sustainable urbanism and smart/data-driven urbanism, it is primarily from a sustainable urbanism angle. That is to say, it would be more appropriate for giving sustainable urbanists a vantage on smart/data-driven urbanism than giving urban scientists a vantage on sustainable

urbanism. Nonetheless, it contains value-laden knowledge and technology of high relevance to urban scientists.

I consider that this book represents a basis for further discussions to debate the point that big data analytics and the IoT have disruptive, substantive, and synergetic effects, particularly on forms of sustainable urban planning and development. In the meantime, this book seeks to encourage in-depth research, thorough qualitative analyses and empirical investigations, focused on establishing, substantiating, and/or challenging the assumptions and claims made by the advocates of big data analytics and the IoT as to advancing sustainability.

This book offers a novel, fresh, all-embracing approach to sustainable urbanism. In doing so, it combines scientific, academic, and practical relevance with cross-domain analyses in regard to the tripartite composition of sustainable development—environmental, economic, and social sustainability, supported with critical and reflective thinking.

Advances in the Leading Paradigms of Urbanism and their Amalgamation is intended for several classes of readers, including students, researchers, academics, urban scientists, social scientists, futurists, technologists, ICT experts, urbanists, planners, engineers, architectural designers, built and natural environment specialists, and policy analysts and policymakers, whether they are new to or already involved in sustainable urbanism as a field for research and practice. It is also intended for all of those interested in an overview covering a range of topics on the prevailing models of sustainable urbanism and their recent data-driven smart incarnation, including the evolving approach to their amalgamation.

Specifically, this book can be read on two different levels. In other words, it has been written with two kinds of readers in mind. The first group of readers will be represented by students, scholars, and professionals. I am writing to students taking graduate and postgraduate courses or pursuing Master's and Ph.D. programs in the areas of sustainable cities, smart cities, smart sustainable cities, sustainable urban planning, sustainable development, urban science, urban informatics, urban computing, and so forth. Those readers already familiar with sustainable cities and smart cities and their relationship in the context of sustainability and with the growing role of big data analytics and the IoT in improving 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 knowledge in this particular area are provided and supported with a detailed explanation and discussion of the relevant conceptual, theoretical, disciplinary, and practical foundations with reference to sustainable urbanism as an interdisciplinary field. This is meant to appease the uninitiated readers. The second group of readers will be presented by intellectuals and people with a limited, if any, scientific background. Throughout, the book has been written with this audience in mind. At times, the content presented might seem overwhelming, and I hope that you won't be easily discouraged. Even if the scientific content of a given chapter is difficult to understand, the citations from original documents, conclusions drawn, and recommendations made can be easily comprehended. I believe that this book will be a very useful resource for all of those involved or with interest in sustainable smart urbanism that are looking for an accessible reference. Overall, people in many disciplines and professional fields will find the coverage of the scientific shifts and practical advancements related to this field to be of great value and usefulness. My hope is that this book will be of interest to people of other countries than the ecologically advanced nations, which are the focus of the empirical investigation in this work.

I believe that I have achieved an important goal with this book—by creating a valuable, strategic resource for the different communities in the field of sustainable urbanism. Especially, there is a need for a comprehensive book on sustainable urbanism given that this field is remarkably heterogeneous, with a large number and wide variety of unaddressed and unsettled questions in research and with a host of unexplored opportunities toward new approaches in light of the recent advances in planning and development practices as well as in technology and its application.

Finally, I will be pleased if this book contributes to a better understanding of sustainable urbanism, and, more importantly, stimulates the development and implementation of new faces of smart sustainable cities and thereby mitigates or overcomes the extreme fragmentation of and the weak connection between sustainable cities and smart cities as landscapes and approaches, respectively. It is my anticipation that the practical and conceptual advances presented here will stimulate diverse future research and inform policy recommendations on integrating compact, ecological, and data-driven approaches for societal transitions. All in all, I hope that this book will be enlightening, thought-provoking, and making good reading for the target audiences. And ultimately, the first edition will be well received and widely read.

Lund, Sweden Simon Elias Bibri
May 2019

Contents

About the Author

Dr. Simon Elias Bibri is Assistant Professor at the Norwegian University of Science and Technology (NTNU), Department of Computer Science and Department of Architecture and Planning, Trondheim, Norway. His intellectual pursuits and endeavors have resulted in an educational background encompassing knowledge from, and meta-knowledge about, different academic 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. Master of Science with a major in economics and management
12. Ph.D. in computer science and urban planning with a focus on 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 IT 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, green innovation, sustainable business model innovation, and green ICT strategies.

Bibri's current research interests include sustainable smart urbanism, sustainable urbanism, data-driven smart urbanism, scientific urbanism, complexity science, urban science, and data-intensive science, as well as big data computing and its core enabling and driving technologies, namely sensor infrastructures, data processing platforms, cloud and fog computing models, and communication networks.

Bibri has a genuine interest in the interdisciplinary and transdisciplinary research. His general research interests fall within the following areas:

- ICT of ubiquitous computing (i.e., Ambient Intelligence, the IoT, and Sentient Computing)
- Big data science and analytics
- Sustainable cities (e.g., compact city, eco-city, green city, environmental city, symbiocity)
- Smart cities (e.g., real-time city, data-driven city, ambient city, ubiquitous city, sentient city)
- Sustainability transitions and socio-technical shifts
- Philosophy of science and scientific and epistemological paradigm shifts
- Science, technology, and society (STS)
- Technological innovation systems
- Industrial ecology (e.g., industrial symbiosis, eco-industrial parks)
- Environmental and technology policies.

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

1. The Human Face of Ambient Intelligence: Cognitive, Emotional, Affective, Behavioral and Conversational Aspects, Springer, 07/2015
2. The Shaping of Ambient Intelligence and the Internet of Things: Historico–epistemic, Socio-cultural, Politico-institutional and Eco-environmental Dimensions, 11/2015
3. Smart Sustainable Cities of the Future: The Untapped Potential of Big Data Analytics and Context-Aware Computing for Advancing Sustainability, Springer, 03/2018
4. Big Data Science and Analytics for Smart Sustainable Urbanism: Unprecedented Paradigmatic Shifts and Practical Advancements, Springer, 05/2019
5. Advances in the Leading Paradigms of Urbanism and their Amalgamation: Compact Cities, Eco-cities, and Data-Driven Smart Cities, Springer, 05/2020.

1 Introduction: Sustainable Urbanism and the Potential of its Synergic Integration with Data-Driven Smart Urbanism

1.1 Research Topic: A Broad Perspective

Sustainable development has, since its widespread diffusion in the early 1990s, significantly positively influenced urban planning and development. As a result of reviving the discussion about the built form of cities and giving a major stimulus to the question of the contribution that certain urban forms might make to sustainability, sustainable development has undoubtedly inspired a whole generation of urban scholars and practitioners into a quest for the immense opportunities and fascinating possibilities that could be explored by, and the enormous benefits that could be realized from, the planning and development of sustainable urban forms. That is to say, forms for human settlements that will meet the requirements of sustainability and enable the built environment to function in ways that enhance and optimize urban systems and services in line with the goals of sustainable development in terms of reducing material use, lowering energy consumption, mitigating pollution, and minimizing waste, as well as improving social equity and well-being (Bibri and Krogstie 2019a, b).

Sustainable cities have been the leading global paradigm of urbanism for more than three decades thanks to the models of sustainable urban form proposed as new frameworks for restructuring and redesigning urban places to make living more sustainable. Indeed, significant advances in some areas of knowledge about sustainability and a multitude of exemplary practical initiatives have been realized, thereby raising the profile of sustainable cities worldwide. The subject of "sustainable cities" remains endlessly fascinating and enticing, as there are numerous actors involved in the academic and practical aspects of the endeavor, including planners and architects, green technologists, built and natural environment specialists, environmental and social scientists, and, more recently, ICT experts and urban scientists. All these actors are undertaking research and developing strategies to tackle the challenging elements of sustainable urbanism. In addition to this is 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 in sustainable cities. A number of recent United Nations reports and policy papers argue that the compact city and the eco-city as models of sustainable urban form have positive effects on resource efficiency, climate change, economic development, social integration and cohesion, citizen health and quality of life, and cultural dynamics. These two models are the most prevailing approaches to sustainable urbanism and thus promoted by global and local policies as the preferred responses to the challenges of sustainable development. It is argued that the compact city strategies are able to achieve all of the benefits of sustainability, thereby providing an all-encompassing concept for urban planning practices, and that the eco-city strategies are able to deliver positive outcomes in terms of providing healthy and livable human environments in conjunction with minimal demand on resources and thus minimal environmental impacts.

The change is still inspiring and the challenge continues to induce scholars, practitioners, and policymakers to enhance the predominant models of sustainable urban form, or to propose new integrated ones in response to global shifts. Especially, sustainable cities have been problematic, whether in theory or practice (Bibri 2019a, 2020, Bibri et al. 2020), so is yet knowing to what extent we are making progress toward urban sustainability. In other words, despite the benefits claimed by the advocates of the compact city and eco-city models, their critics highlight a number of conflicting and contentious issues, coupled with a number of problems, issues, and challenges. Hence, much more needs to be done considering the very fragmented picture that arises of change on the ground in the face of the expanding urbanization. In this context, it has been suggested that sustainable cities need to embrace and leverage what advanced ICT has to offer so as to improve, advance, and maintain their contribution to sustainability. In a nutshell, new circumstances require new responses.

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The spread of urbanization and the rise of ICT are important global shifts at play across the world today. They are drastically changing our understanding of sustainability in cities. The transformative force of urbanization and ICT, coupled with the central role that cities can play in achieving the goals of sustainable development, has far-reaching implications for societies. By all indicators, the urban world will become largely technologized and computerized 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 addressing many of the conundrums posed, the issues raised, and the challenges presented by urbanization. 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 wicked problems involved in urban planning, development, management, and governance, notably in the context of sustainability. This is another macro–shift at play across the world today. In the current climate of the unprecedented urbanization and increased uncertainty of the world, it may be more challenging for cities in developed countries to configure themselves more sustainably. The predicted 70% rate of urbanization by 2050 reveals that the sustainability of urban environments will be a key factor in the global resilience to forthcoming changes. This implies that the city governments will face significant challenges pertaining to environmental, economic, and social sustainability due to the issues engendered by urban growth. These include increased energy consumption, pollution, toxic waste disposal, resource depletion, inefficient management of urban infrastructures and facilities, inadequate planning processes and decision-making systems, poor housing and working conditions, saturated transport networks, endemic congestion, and social inequality and vulnerability. In a nutshell, urban growth raises a variety of problems that tend to jeopardize the sustainability of cities, as it puts an enormous strain on urban systems and processes as well as ecosystem services. In other words, the multidimensional effects of unsustainability in modern cities are most likely to exacerbate with urbanization.

1.2 Background

There is an increasing recognition that advanced ICT constitutes a promising response to the challenges of sustainable development due to its tremendous, yet untapped, potential for solving many environmental and socio-economic problems. Therefore, ICT has come to the fore and become of crucial importance for containing the effects of urbanization and facing the challenges of sustainability, including the context of sustainable cities which are striving to enhance their contribution to the goals of sustainable development. The use of advanced ICT in sustainable 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, as well as designs, strategies, and policies. Currently, sustainable cities are associated with a number of deficiencies, limitations, challenges, fallacies, and uncertainties when it comes to their planning, development, and governance in the context of sustainability (e.g., Bibri 2020, Bibri and Krogstie 2017a, b, 2019a, b; Kramers et al. 2016; Neuman 2005; Neuman and Jennings 2008; Rapoport and Vernay 2011; Williams 2010). This pertains mostly to the question of how sustainable urban forms should be monitored, understood, analyzed, and thus planned and designed in order to enhance their sustainability performance as to urban systems and services. The underlying argument is that more sophisticated approaches and innovative solutions are needed to overcome the kind of wicked problems and complex challenges pertaining to urban processes and practices in the context of sustainability. This brings us to the issue of sustainable cities and smart cities being extremely fragmented as landscapes and weakly connected as approaches to urbanism (e.g., Angelidou et al. 2017; Bibri 2019a; Bibri and Krogstie 2017a; Bifulco et al. 2016), despite the proven role of advanced ICT and the untapped potential of big data analytics for advancing sustainability under what is labeled "smart sustainable cities" (Bibri 2018a, b). In particular, tremendous opportunities are available for utilizing big data technologies and their novel applications in sustainable cities to improve, advance, and maintain their contribution to the goals of sustainable development. Big data technologies have become essential to the functioning of sustainable cities (Bibri 2019a, b) as well as smart cities (Kitchin 2014, 2016) in relation to sustainability (Batty et al. 2012; Bibri 2019c, Bibri and Krogstie 2020b). Consequently, urban processes and practices are becoming highly responsive to a form of data-driven urbanism. In more detail, we are moving into an era where instrumentation, datafication, and computation are routinely pervading the very fabric of cities, coupled with the integration and coordination of their systems and domains. And consequently, vast troves of data are generated, analyzed, harnessed, and exploited to control, manage, organize, and regulate urban life. This data-driven approach to urbanism is increasingly becoming the mode of production for smart sustainable cities.

Smart cities are increasingly connecting the ICT infrastructure, the physical infrastructure, the social infrastructure, and the economic infrastructure to leverage their collective intelligence, thereby striving to render themselves more sustainable, efficient, functional, resilient, livable, and equitable. As such, they seek to solve a fundamental conundrum—ensure sustainable economic development,

social equity, and enhanced quality of life at the same time as reducing costs and increasing resource efficiency and environment and infrastructure resilience. This is increasingly enabled by utilizing a fast-flowing torrent of urban data and the rapidly evolving big data technologies and thus algorithmic planning and governance, networked urban systems, and coordinated urban domains. In particular, the generation of colossal amounts of urban data and the development of sophisticated data analytics techniques for monitoring, understanding, analyzing, managing, regulating, and planning the city are the most significant aspects of smart cities that are being embraced and leveraged by sustainable cities in their endeavor to enhance their contribution to sustainability. For supra-national states, governments, and city officials, smart cities offer the enticing potential of environmental improvement and socio-economic development, and the renewal of urban centers as hubs of innovation and research (e.g., Batty et al. 2012; Bibri 2019b; Kitchin 2014; Kourtit et al. 2012; Townsend 2013). While there are several main characteristics of smart cities as evidenced by industry and government literature (e.g., Holland 2008), the one that this book is concerned with is environmental and social sustainability on the basis of big data analytics and its novel applications.

In light of the above, there has recently been a conscious push for cities across the globe to be smarter and more sustainable by developing and implementing big data technologies and their novel applications in relation to various urban domains to enhance and optimize designs, strategies, policies, and hence operations, functions, and services. In this respect, a number of research endeavors have started to focus on smartening up sustainable cities by amalgamating the landscapes of and the approaches to sustainable cities and smart cities in a variety of ways in the hopes of reaching the required level of sustainability, focusing mainly on the "eco-city" and "sustainable city" initiatives in their more recent data-driven smart incarnations. Numerous research opportunities are available and can be realized in the ambit of data-driven smart sustainable cities. To put it differently, there is a host of unexplored horizons toward new approaches to urbanism in order to mitigate or overcome the extreme fragmentation of and the weak connection between sustainable cities and smart cities, in particular on the basis of big data computing and the underpinning technologies (Bibri 2019a). The underlying assumption is that the evolving big data deluge with its extensive sources hides in itself the answers to the most challenging analytical questions as well as the solutions to the most complex challenges pertaining to sustainability in the face of urbanization. It also plays a key role in understanding urban constituents as data agents. Many urban development approaches emphasize the role of big data technologies and their novel applications as an advanced form of ICT in improving sustainability performance (e.g., Al Nuaimi et al. 2015; Batty et al. 2012; Bettencourt 2014; Bibri 2018b, 2019b; Bibri and Krogstie 2020a, b, Pantelis and Aija 2013; Shahrokni et al. 2015a, b).

One of the salient driving factors for urbanism embracing the wave of integrating data-driven smartness with sustainability lies in the opportunities 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 being enabled by big data technologies for data acquisition, storage, management, processing, and analysis that are applied for supporting the goals of sustainable development and thus advancing sustainability. This is manifested in the rapid evolvement of smart sustainable cities as a new approach to and a leading paradigm of urbanism into becoming more and more digitally instrumented, datafied, and computerized, thereby becoming data-analytically driven with respect to urban processes and practices in the context of sustainability and the integration of its dimensions. In several ecologically and technologically advanced countries, national urban projects are investing heavily in, and focusing on strengthening the role of, big data technologies and their novel applications in urban planning and development. This approach is understood as what sustainable cities are doing to improve their sustainability performance and how they do it, on the one hand, and what smart cities are doing to incorporate the goals of sustainable development and how they do it, on the other hand. Accordingly, the scholarly enterprise of big data computing and the role of its uses in facilitating the contribution of both sustainable cities and smart cities to sustainability is most likely to represent an important changing dynamic in the transition toward data-driven smart sustainable cities. This approach to urbanism entails harnessing ideas about how new technologies can be directed toward creating more effective ways of leveraging data and how new data-driven innovations can be facilitated and diffused throughout urban systems and domains for stimulating drastic transformations. One key facet in this regard is how to improve the three dimensions of sustainability by successfully translating it into the built, spatial, operational, functional, and serviceable forms of the city.

In view of the above, the field of sustainable urbanism needs to extend its boundaries and broaden its horizons beyond the ambit of the built form and ecological design of the city to include technological innovation opportunities and computational capabilities by unlocking and exploiting the potential of advanced ICT. Besides, science and technology are well aligned with the project of envisioning alternative societal and urban futures, and entails a well-established dynamic interplay with societal progress and urban innovation. Specifically, visions of future

advances in science and technology inevitably bring with them wide-ranging common visions on how societies, and thus cities as social organizations, will evolve in the future, as well as the opportunities and risks this future will bring (Bibri 2019d, Bibri and Krogstie 2016).

At the beginning of a new decade, we have the opportunity to look forward and consider what we could achieve in the coming years in the era of big data revolution. Again, we have the chance to consider the desired future of data-driven smart sustainable cities. This will motivate many urban scholars, scientists, and practitioners to think about how the subject of "data-driven smart sustainable cities" might develop, and inspire them into a quest for the possibilities that can be created by the development and implementation of such cities. In this respect, we are in the midst of an expansion of time horizons in city planning. Sustainable cities look further into the future when forming strategies, and the movement toward a long-term vision arises from three major mega trends that shape our societies at a growing pace: sustainability, ICT, and urbanization. Recognizing a link between these trends, sustainable cities across the globe have adopted ambitious goals that extend far into the future and have developed different pathways to achieve them (Bibri and Krogstie 2019b).

1.3 The Aim and Purpose of the Book

Integrating and fusing theoretical and practical perspectives from a number of city-related fields and scientific disciplines, this book explores the recent advances in the leading paradigms of urbanism, namely compact cities, eco-cities, and data-driven smart cities, and the evolving approach to their amalgamation under the umbrella term of smart sustainable cities. It addresses these advances by investigating how and to what extent the strategies of compact cities and eco-cities and their merger have newly been enhanced and strengthened through planning and development practices, and are being harnessed and leveraged by the technology solutions pertaining to data-driven smart cities. The ultimate goal is to improve sustainability and enable its synergistic effects on multiple scales. This entails developing and implementing more effective ways to contribute to, and support the balancing between, the three goals of sustainability, as well as to produce combined effects of the strategies and solutions of the three currently prevailing approaches to urbanism that are greater than the sum of their separate effects in terms of the tripartite value of sustainability.

Taking the above into account, this book brings together the academic and scientific disciplines underlying sustainable urbanism, which underpin the understanding, development, application, and integration of design and technology, to improve and maintain the contribution of sustainable cities to the goals of sustainable development over the long run toward achieving sustainability. In doing so, it highlights the need to consider the science and technology for environmental, economic, and social benefits, as well as the environmental, economic, and social evidence for the uptake of advanced technologies.

1.4 The Structure and Content of the Book

The book comprises 8 chapters. This chapter opens the subject of sustainable urbanism with a broad view, displaying the multifaceted knowledge of the subject matter that will inform the reading of it. It provides a platform to establish the tone of this book and to set the scene. As such, it covers research topic, background, as well as the aim, structure, content, organization, and design of the book. The main topics, concepts, research issues, knowledge gaps, opportunities, and prospects pointing to a need for elaboration or investigation in relevance to the scope of this book are introduced in this chapter and then developed further or addressed in more details in the subsequent chapters.

Chapter 2 provides a comprehensive state–of–the–art review of compact urbanism as a set of planning and development practices and strategies, focusing on the three dimensions of sustainability and the significant, yet untapped, potential of big data technology for enhancing such practices and strategies under what is labelled "data–driven smart sustainable urban form."

Chapter 3 examines how the compact city model is practiced and justified in urban planning and development. In this regard, it seeks to answer these two questions: What are the prevalent design principles and strategies of the compact city model, and in what ways do they mutually complement one another in terms of producing the expected benefits of sustainability? To what extent does the compact city model support and contribute to the environmental, economic, and social goals of sustainable development?

Chapter 4 provides a comprehensive state-of-the-art review of the field of ecological urbanism in relation to sustainable urbanism and data-driven smart urbanism. In doing so, it addresses the conceptual, theoretical, discursive, and practical dimensions of these approaches to urbanism; the multiple and diverse models, design principles and strategies, and ideals and benefits of ecological urbanism; the key deficiencies, challenges, uncertainties, and opportunities pertaining to sustainable urbanism; as well as new frameworks for data-driven smart sustainable/ecological urbanism. This is further supported by a critical discussion with respect to Science, Technology, and Society linkages and concerns.

Chapter 5 examines how the eco-city model and especially its three sustainability dimensions are practiced and

justified in urban planning and development at the local level as motivated by the increased interest in developing sustainable urban districts. In this light, it seeks to answer these two questions: What are the key strategies of the eco-city district model, and in what ways do they mutually complement one another in terms of producing the expected benefits of sustainability? To what extent does the eco-city district model support and contribute to the environmental, economic, and social goals of sustainability?

Chapter 6 is important from a conceptual standpoint. It sheds light on the kind of wicked problems that are associated with sustainable urbanism and its smart dimension, and explores the usefulness of big data uses within this domain. Further, it analyzes the role of urban science and data-intensive science, as informed and enabled by big data science and analytics, respectively, in transforming what has been termed as urban sustainability science as an integrated scientific field. In so doing, it offers a conceptual framework for integrating all the ingredients.

Chapter 7 sets forth a conceptually new framework according to which urban intelligence functions should be developed and applied based on the recent advances in big data science and analytics and the underpinning technologies to facilitate urban sustainability transitions. Specifically, it looks at data-driven smart sustainable urbanism, with a focus on new urban intelligence functions and related processes, systems, and sciences. Further, it proposes and illustrates a novel framework for data-driven smart sustainable cities on the basis of advanced technologies and data-intensive approaches to science.

Chapter 8 provides a state-of-the-art review of the IoT and big data analytics in terms of their core enabling technologies, infrastructures, and applications within smart cities and smart sustainable cities. Further, it proposes an integrated framework for smart sustainable cities, which is intended to illustrate how the informational landscape of smart cities based on the IoT and big data analytics could enhance the physical landscape of sustainable cities as to their strategies in ways that can enhance their sustainability performance on the basis of the IoT-enabled big data applications.

Chapter 9 investigates how the emerging data-driven smart city is being practiced and justified in terms of the development and implementation of its innovative applied solutions for advancing sustainability. In this light, the focus will be on the core features characterizing this emerging paradigm of urbanism, namely technologies, applications, competences, infrastructure, and data sources in the context of London and Barcelona as the leading data-driven smart cities in Europe.

Chapters 10 sets out to identify and integrate the underlying components of a novel model for data-driven smart sustainable cities of the future. This entails amalgamating the leading paradigms of urbanism in terms of their strategies and solutions, namely compact cities, eco-cities, and data–driven smart cities. This is grounded in the outcome of six case studies conducted on these cities. This empirical research is part of an extensive futures study whose aim is to analyze, investigate, and develop a novel model for data-driven smart sustainable cities of the future using a backcasting approach. This chapter thus reports the outcome of Step 5 of this backcasting study: specify and merge the underlying components of the socio–technical system to be developed by answering 4 guiding questions have a standardized scholarly research structure, which makes them easy to navigate and read. Specifically, these chapters are presented and structured in the form of journal articles consisting of abstract, introduction, analysis, discussion, and conclusion. Most of them include research methodologies together with conceptual, theoretical, and disciplinary foundations.

1.5 The Organization and Design of the Book

This book has been 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, sustainable urbanism and its data-driven smart dimension, or with deep curiosity about big data computing as a disruptive technology and its far-reaching implications for urban sustainability. 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 various 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 the topic on focus. 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. Therefore, as to how relevant and important the topics of the book are, the choice is yours—based on your own assessment and interpretation.

To facilitate embarking on exploring the field of sustainable urbanism, this book has been designed around three related aims, namely:

1. To help the reader gain essential underpinning knowledge about the compact, ecological, and data-driven approaches to sustainable urbanism.
2. To enable the reader to develop a broader understanding of the emerging integrative approach to the leading paradigms of urbanism, as they make connections between their own understandings of the current challenges pertaining to sustainability and urbanization and the evolving urban transformation being instigated by big data analytics and the IoT and advanced urban planning and design practices.
3. To encourage the reader to take part in the ongoing debate about sustainable urbanism in the era of big data and pervasive computing and the ensuing datafication of the contemporary city. The data avalanche is here.

This book has been carefully designed to provide the repository of knowledge required to explore the realm of compact, ecological, and data-driven paradigms of urbanism from a holistic perspective. This is an extremely complex, dynamic, and challenging area of thinking and practice, and hence, it is well worth exploring it in some depth and from a multi-perspectival approach. The best way to enable the reader to embark on such an exploration is to seamlessly integrate multiple theories and practices and to harness this integration in relevance to sustainability and its advancement in a rather unified analysis, synthesis, evaluation, and implementation. Achieving this kind of amalgamation in the form of a systematic investigation 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 shifts and technological innovations and their role in and potential for advancing sustainable cities 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 the expanding urbanization through integrating the prevailing models of sustainable urbanism. This is meant to offer the people of the ecologically advanced nations the resources with which to evaluate the opportunities for sustainable cities to win the battle of sustainability and to tackle the pressure of urbanization in the years ahead. This is believed to be an important achievement in its own right, and certainly makes this book a rewarding learning experience for those who feel they could deepen their understanding of sustainable urbanism and its data-driven smart dimension. 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 analytics and the IoT, 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.

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2 The Compact City Paradigm and its Centrality in Sustainable Urbanism in the Era of Big Data Revolution: A Comprehensive State-of-the-Art Literature Review

2.1 Introduction

Sustainable cities have been the leading global paradigm of urban planning and development (e.g., Bibri 2019a; Jabareen 2006; Van Bueren et al. 2011; Wheeler and Beatley 2010; Whitehead 2003; Williams 2009a, b) for more than three decades. They represent an umbrella term for various models of sustainable urban forms, including compact cities. In the early 1990s, the discourse on sustainable development produced the notion of compact city planning and development that became a hegemonic response to the challenges of sustainable development (Jenks and Dempsey 2005) by focusing on intensification, creating limits to urban growth, encouraging mixed use and diverse development, and placing a greater focus on the role of public transportation and quality of urban design (Arbury 2005). In the EU Green Paper of the Urban Environment, the compact city model was advocated as the most sustainable for urban development (CEC 1990). Indeed, according to many studies (e.g., Bibri and Krogstie 2017b; Jabareen 2006; Næss 2013; Newman and Kenworthy 1999), the compact city can promote sustainability by reducing the amount of travel and shortening commute time; decreasing car dependency; lowering per capita rates of energy use; limiting the consumption of building and infrastructure materials; mitigating pollution; maintaining the diversity for choice among workplaces, service facilities, and social contacts; and limiting the loss of green and natural areas. Cities can harness the advantages of agglomeration and tap into the tremendous variety of benefits that compact cities have to offer through proper planning, development, and governance. In particular, cities as the most compact settlements of people have a tremendous effect on environmental changes (Girardet and Schumacher 1999), and low population density is the most environmentally harmful form in urban structures (UN-Habitat 2014b).

The benefits of compact cities, as research from around the globe suggests, are not guaranteed as desired outcomes. This relates to the issues argued against by the critics of the compact city model that should be addressed so that this model can gain in more popularity. By and large, most of these issues pertain to the unforeseen consequences and unanticipated effects of compact cities that fall under what is called in urban planning "wicked problems," a term that has gained more currency in urban policy analysis after the adoption of sustainable development within urban planning since the early 1990s, and that are often overlooked because of failing to approach compact cities from a holistic approach, or to treat them in too immediate and simplistic terms. Rittel and Webber (1973), the first to define the term, associate wicked problems with urban planning, arguing that the essential character of wicked problems is that they cannot be solved in practice by a central planner. Such problems are so complex and dependent on so many factors that it is hard to grasp what exactly the problem is, or how to tackle it. In other words, they are difficult to explain and impossible to solve because of incomplete, contradictory, and changing requirements that are not easy to recognize.

In addition, in the current climate of the unprecedented urbanization and increased uncertainty of the world, it may be more challenging for cities in developed countries to configure themselves more sustainably. The predicted 70% rate of urbanization by 2050 (UN 2015) reveals that the sustainability of the urban environment will be a key factor in the global resilience to forthcoming changes. This implies that the city governments will face significant challenges pertaining to environmental, economic, and social sustainability due to the issues engendered by urban growth. These include increased energy consumption, pollution, toxic waste disposal, resource depletion, inefficient management of urban infrastructures and facilities, inadequate planning processes and decision-making systems, poor housing and

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working conditions, saturated transport networks, endemic congestion, and social inequality and vulnerability (Bibri 2019a; Bibri and Krogstie 2017a). In a nutshell, urban growth raises a variety of problems that tend to jeopardize the sustainability of cities, as it puts an enormous strain on urban systems and processes as well as ecosystem services.

Against the backdrop of the unprecedented rate of urbanization and the mounting challenges of sustainability, an array of alternative ways of planning, designing, managing, and governing cities based on advanced ICT has materialized and is rapidly evolving, providing the raw material for how sustainable urban forms as leading paradigms of sustainable urbanism can improve, advance, and maintain their contribution to the goals of sustainable development (Bibri 2018b, 2019a, b, c; Bibri and Krogstie 2017c), as well as for how smart cities can transition toward the needed sustainable development (e.g., Al Nuaimi et al. 2015; Batty et al. 2012). These two main urbanism approaches: sustainable cities and smart cities, as a set of interrelated practices have been developing for quite some time: since the diffusion of sustainable development around the early 1990s and the prevalence of ICT around the mid-1990s, respectively. But what is presently new is that the emerging initiatives and endeavors are shifting from merely focusing on the application of sustainability knowledge to city planning and design or the development and implementation of smart technologies to optimize these urban practices to integrating the sustainable city and the smart city as both landscapes and approaches. (Bibri 2019f).

There is an increasing recognition that advanced ICT constitutes a promising response to the challenges of sustainable development in the face of urbanization due to its tremendous, yet untapped, potential for solving many socio-economic and environmental problems (see, e.g., Angelidou et al. 2017; Batty et al. 2012; Bibri and Krogstie 2017a, 2019a, b; Höjer and Wangel 2015; Kramers et al. 2016). Therefore, advanced ICT has recently come to the fore and become of fundamental importance as to mitigating the negative effects of urbanization and tackling the conundrums of sustainability. Many urban development approaches emphasize the role of big data technologies and their novel applications as an advanced form of ICT in advancing sustainability (e.g., Al Nuaimi et al. 2015; Batty et al. 2012; Bettencourt 2014; Bibri 2018b, 2019a, b, c; Pantelis and Aija 2013). Indeed, there has recently been a conscious push for cities across the globe to be smarter and more sustainable by developing and implementing big data technologies and their novel applications in relation to various urban domains to enhance and optimize urban designs, strategies, and policies, operations, functions, and services.

A large body of work has investigated the presumed outcome of the compact city model achieved through planning practices and development strategies. More specifically, scholars have discussed to what extent this model of sustainable urban form produce the claimed environmental, economic, and social benefits of sustainability (Jenks and Jones 2010; Lin and Yang 2006; Burton 2002). Here the focus is often on the design principles and strategies underlying the compact city model (Bibri and Krogstie 2017b; Boussauw et al. 2012; Dumreicher, Levine and Yanarella 2000; Jabareen 2006; Kärrholm 2011; Van Bueren et al. 2011; Williams et al. 2000). This line of research directs attention to their link to the goals of sustainable development as to its tripartite composition. A recent wave of research has moreover started to focus on integrating these design principles and strategies with advanced ICT, notably big data technology and its novel applications, to improve the contribution of sustainable urban forms to sustainability (e.g., Bibri 2018b, 2019a; Bibri and Krogstie 2017b, 2019a, b). This line and wave of research opens the way for cross-domain analyses in terms of integrating physical, spatial, environmental, economic, social, cultural, technological, and scientific aspects. This chapter follows this path by providing a comprehensive state–of–the–art review of compact urbanism as a set of planning and development practices and strategies, focusing on the three dimensions of sustainability and the significant, yet untapped, potential of big data technology for enhancing such practices and strategies under what is labeled "data-driven smart sustainable urbanism." Specifically, it seeks to answer the following questions:

1. What are the prevalent design principles and strategies underlying the compact city model, and in what ways do they mutually complement and beneficially affect one another?
2. What kind of conflicts and contentions does the compact city model raise, and how can they be explained?
3. To what extent does the compact city model contribute to the environmental, economic, and social goals of sustainable development?
4. What kind of problems, issues, and challenges do pertain to the compact city as a model of sustainable urban form, and what is the potential and role of of big data technology in solving or mitigating them?

In doing so, this interdisciplinary review endeavors to deliver a detailed analysis, critical evaluation, and well-worked out discussion of the available qualitative and quantitative research covering the topic of compact cities and the broader field within which it falls: sustainable urbanism, including its data-driven smart urbanism. The main added value of this work lies in its thoroughness, comprehensiveness, topicality, and original contribution in

the form of new insights and perspectives as a result of synthesizing a large body of interdisciplinary work on the leading paradigms of urbanism: sustainable cities and data-driven smart cities. The latter pertains to the potential and role of big data technology and its novel applications in enhancing and optimizing urban operations, functions, designs, strategies, and policies beyond the ambit of the built form.

This chapter unfolds as follows. Section 2.2 outlines the literature review methodology in terms of category, search strategy, selection criteria, organizational approach, and purpose. In Sect. 2.3, the relevant conceptual, theoretical, and discursive foundations are introduced, described, and integrated. Section 2.4 provides a thorough analysis, evaluation, and discussion of the compact city as a leading paradigm of sustainable urbanism and its relation to data-driven smart urbanism. Finally, this chapter concludes, in Sect. 2.5, by summerizing the key findings, providing some reflections, highlighting the key contributions, and suggesting some future research avenues.

2.2 Literature Review Methodology: A Topical Approach

This interdisciplinary review involves the exploration of a vast and diverse array of literature on the topic (including journal articles, conference proceedings, books, reports, and dissertations) of compact cities, integrating various disciplinary fields while putting an emphasis on the qualitative research in the field. Interdisciplinarity has become a widespread mantra for research within diverse fields, accompanied by a growing body of academic publications. The field of sustainable urban forms is profoundly interdisciplinary in nature, so too is the research within, and thus literature on, it. This scholarly perspective also applies to any review of this literature in the sense of using insights and methods from several disciplines. These include, but are not limited to: urban planning and development, sustainable development, science and technology, geography, ecology, environmental science, economics, and policy and politics. Accordingly, this interdisciplinary literature review is a topical, analytical, and organizational unit that is justified by the nature and orientation of the research field of sustainable urban forms. Adopting a topical approach to this review is thus deemed more relevant than a systematic one, and this chapter determines the usefulness of this substantive category of review.

A review method was developed as a means to indicate the issues to be addressed, search strategy for retrieving the sought articles and other documents, inclusion and exclusion criteria for identifying and selecting the relevant ones, and abstract review protocols.

2.2.1 Hierarchical Search Strategy and Scholarly Sources

A literature search is the process of querying quality scholarly literature databases to gather applicable research documents related to the topic under review. A broad search strategy was used, covering several electronic search databases, including Scopus, ScienceDirect, SpringerLink, and Sage Journals, in addition to Google Scholar. The main contributions came from the leading journal articles in relevance to the topic on focus. The hierarchical search approach to searching for literature involved the following:

- Searching databases of reviewed high-quality literature;
- Searching evidence-based journals for review articles; and
- Routine searches and other search engines.

In addition, the collection process is based on Scott's (1990) four criteria for assessing the quality of the sought material, namely:

1. Authenticity: the evidence gathered is genuine and of unquestionable origin
2. Credibility: the evidence gathered is free from error and distortion
3. Representation: the evidence obtained is typical
4. Meaning: the evidence gathered is clear and comprehensible.

2.2.2 Selection Criteria: Inclusion and Exclusion

To find out what has already been written on the topic of compact cities, the above search approach was adopted with the objective to identify the relevant studies addressing the diverse research strands that cover the questions this chapter intends to answer in relevance to the empirical study to be conducted. Therefore, the preliminary selection of the available material was done in accordance to the problems under investigation, using a variety of sources. This is underpinned by the recognition that once the research problems are set, it becomes possible to refine and narrow down the scope of reading, although there may seem to be a number of sources of information that appear pertinent. With that in mind, for a document to be considered in terms of its ability to provide any information of pertinence, it should

pertain to one of the conceptual/theoretical subjects and thematic/topical categories specified in accordance with the questions to be answered as representing in this context the headings of the sections and subsections of this chapter. The focus was on the documents that provided definitive primary information typically from a cross-domain analysis perspective. While certain methodological guidelines were deemed essential to ensure the validity of the review, it was of equal importance to allow flexibility in the application of the topical literature review approach to capture the essence of the research within the interdisciplinary field of sustainable urban forms, with a focus on compact cities. The whole idea was to "accumulate a relatively complete census of relevant literature" (Webster and Watson 2002, p. 16). On the whole, scoring the documents was based on the inclusion of issues related to the topic on focus. Conversely, the documents excluded were those that did not meet the specific criteria in terms of their relevance to the questions being addressed. As to abstract review, the abstracts were reviewed to assess their pertinence to the review and to ensure a reliable application of the inclusion and exclusion criteria. Inclusionary discrepancies were resolved by the re-review of abstracts. The process allowed to further refine and narrow down the scope of reading.

The keywords searched included "compact city," "compact urban form," "sustainable urban form," "sustainable urban planning," "sustainable cities," "compact city planning," "compact city development," "compact city design," "compact city policy," "compact city dimensions," "sustainable urban development," "urban intensification," "urban densification," "compactness," "urban density," "mixed use development," "land use and sustainable transportation," "sustainable built environment," "sustainable development AND urban form", "sustainable cities AND big data technology," "sustainable urban forms AND big data technology," "sustainable urban development AND big data technology," "smart sustainable cities AND big data applications," "urban planning AND big data analytics AND sustainable development," "data-driven smart sustainable urbanism," and "data-driven smart urbanism AND sustainable development," in addition to some derivatives of these keywords. These were used to search against such categories as the documents' keywords, title, and abstract to produce some initial insights into the topic. To note, due to the limitations associated with relying on the keyword approach, backward literature search (backward authors, backward references, and previously used keywords) and forward literature search (forward authors and forward references) were additionally used to enhance the search approach (Webster and Watson 2002).

2.2.3 Combining Three Organizational Approaches

This literature review is structured using a combination of three organizational approaches, namely thematic, inverted pyramid, and the benchmark studies. That is to say, it is divided into a number of sections representing the conceptual subjects and thematic categories for the topic of compact cities. The analysis, examination, and discussion of the relevant issues is organized accordingly while, when appropriate, starting from a broad perspective and then dealing with a more and more specific one with respect to the selected studies. In doing so, the focus is on the major publications considered as significant in the field.

2.2.4 Purpose

The literature review is typically performed to serve many different purposes. This depends on whether or not it is motivated by, or an integral part of, a research study, as well as on its focus and scope. However, considering the aim of this paper and its relation to the empirical study to be conducted, this review was carried out with the following specific purposes in mind:

- To examine and discuss the underlying conceptual, theoretical, and discursive foundations of the compact city and their integration from an interdisciplinary perspective.
- To analyze, evaluate, and synthesize the existing knowledge in line with such constructs set for the empirical study to be conducted.
- To highlight the strengths, weaknesses, omissions, and contradictions of the existing knowledge, thereby providing a critique of the research that has been done within the field.
- To discuss the identified strengths and weaknesses with respect to the environmental, economic, and social goals of sustainability and the extent to which they are balanced.
- To identify the knowledge gaps and research opportunities within the field.
- To identify the key relationships between the findings of the relevant studies addressing the different strands of the topic on focus by comparing them and linking their results.

2.3 Conceptual, Theoretical, and Discursive Foundations

2.3.1 The Built Environment

The built environment refers to the human-made surroundings that provide the setting for human activity and what this entails in terms of land use, transport systems, and the spatial patterns of physical objects and their design features. It encompasses urban places and spaces created, restructured, and redesigned by people, including buildings, green infrastructure, and public infrastructure. The built environment is at the core of sustainable urban forms in the sense that the latter has emerged to enable the former to function in a sustainably constructive way, for example, to environmentally contribute beneficially to the planet for the present and future generations in terms of reducing material use, lowering energy consumption, mitigating pollution, and minimizing waste. However, the built environment has been referred to by a variety of terms, which tend to be used interchangeably. Handy et al. (2002) describe it as an amalgam of land use, urban design, and the transportation system, including patterns of human activity and mobility within the physical environment. Roof and Oleru (2008) define it as the human-made space in which people live, work, and recreate on a day-to-day basis. Past studies within urbanism have typically focused on different spatial levels of the built environment, including the neighborhood, district, city, and regional scales. For example, Handy et al. (2002) discuss measures of the built environment by categorizing them into neighborhood and regional features, with at least five interrelated and often correlated dimensions of the built environment at the neighborhood scale, as suggested by several studies (Table 2.1).

2.3.2 Sustainable Urban Planning, Design, and Development

Urban planning is concerned with the development and design of land use and the built environment. As a governmental function in most countries, it is practiced on neighborhood, district, municipality, city, metropolitan, regional, and national scales, with land use, environmental, transport, and local planning representing more specialized foci. It has been approached from a variety of perspectives, often combined, including physical, spatial, geographical, ecological, technical, economic, social, cultural, and political. As an interdisciplinary field, it involves transportation planning, environmental planning, land-use planning, policy recommendations, and public administration, as well as strategic thinking, sustainable development, landscape architecture, civil engineering, and urban design (Nigel 2007). Urban planning is associated with different kinds of urban systems, namely:

- Built form (buildings, streets and boulevards, neighborhoods, districts, residential and commercial areas, schools, parks, public spaces, etc.).
- Urban infrastructure (transport systems, water and gas provision systems, sewage systems, power distribution systems, etc.).
- Ecosystem services (energy, water, air, food, climate regulation, etc.).

Table 2.1 Dimensions of the built environment

Dimension	Definition	Exemples
Density and intensity	Amount of activity in a given area	Persons per acre or jobs per square mile Ratio of commercial floor space to land area
Land use mix	Promixity of different land uses	Distance from house to nearest store Share of total land area for different uses Dissimilarity index
Street connectivity	Directness and availability of alternative routes through the network	Intersections per square mile of area Ratio of straight-line distance of network distance Average block length
Street scale	Three-dimensional space along a street as bounded by buildings	Ratio of building heights to street width Average distance from street to buildings
Aesthetic quality	Attractiveness and appeal of a place	Percent of ground in shade at noon Number of locations with graffiti per square mile
Regional structures	Distribution of activities and transportation facilities across the region	Rate of decline in density with distance from downtown Classification based on concentrations of activity and transportation network

Source Handy et al. (2002)

- Human services (public services, social services, cultural facilities, recreational and green spaces, etc.).
- Administration (management, governance, policy, regulatory frameworks, practices, policy design and recommendation, technical and assessment studies, etc.).

Sustainable urban planning is the process of guiding and directing the development and design of land, urban environment, urban infrastructure, and related processes, activities, and services in ways that contribute to sustainable development toward achieving sustainability. As such, it involves defining the long-term goals of sustainability; formulating sustainable development objectives to achieve such goals; arranging the means and resources required for attaining such objectives; and implementing, monitoring, steering, evaluating, and improving all the necessary steps in their proper sequence toward reaching the overall aim (Bibri 2019a).

Urban design is an integral part of urban planning. It is concerned with planning, landscape architecture, and civil engineering, as well as sustainable urbanism, ecological urbanism, sustainable design, ecological design, and strategic design (Bibri and Krogstie 2017a). Dealing with the design and management of the public domain and the way this domain is experienced and used by urbanites, urban design refers to the process of designing, shaping, arranging, and reorganizing urban physical structures and spatial patterns. As to its sustainable dimension, it is aimed at making urban living more environmentally sustainable and urban areas more attractive and functional (e.g., Aseem 2013; Boeing et al. 2014; Larice and MacDonald 2007). In this respect, urban design is about making connections between forms for human settlements and environmental and social sustainability, built environment and ecosystems, people and the natural environment, economic viability and well-being, and movement and urban form.

Urban development refers to urbanization with its different dimensions, notably physical (land-use change), geographical (population), societal (social and cultural change), and economic (agglomeration). Urban planning as a technical and political process is seen as a valuable force to achieve sustainable development through design, among other things. Sustainable urban development can be viewed as an alternative approach to urban thinking and practice. It focuses primarily on addressing and overcoming the escalating environmental problems and the rising socio-economic issues associated with the predominant paradigm of urban development by mitigating or eliminating its negative impacts on the environment and improving human well-being. In short, sustainable urban development is a strategic approach to achieving the long-term goals of sustainability. As such, it requires that scholars, practitioners, organizations, institutions, and governments agree upon concrete ways to determine the most effective approaches and strategic actions in a concerted effort to reach a sustainable future.

2.3.3 Sustainable Cities

There are multiple views on what a sustainable city should be or look like and thus various ways of conceptualizing it. Generally, a sustainable city can be understood as a set of approaches into operationalizing sustainable development in, or practically applying the knowledge about sustainability and related technologies to the planning and design of existing and new cities or districts. It represents an instance of sustainable urban development, a strategic approach to achieving the long-term goals of urban sustainability. Accordingly, it needs to balance between the environmental, economic, and social goals of sustainability as an integrated process. Specifically, as succinctly put by Bibri and Krogstie (2017a, p. 11), a sustainable city "strives to maximize the efficiency of energy and material use, create a zero-waste system, support renewable energy production and consumption, promote carbon-neutrality and reduce pollution, decrease transport needs and encourage walking and cycling, provide efficient and sustainable transport, preserve ecosystems and green space, emphasize design scalability and spatial proximity, and promote livability and community-oriented human environments."

2.3.4 Sustainable Urban Forms

There are different approaches to sustainable cities, which are also identified as models of sustainable urban forms, including compact cities, eco-cities, green cities, new urbanism, landscape urbanism, and urban containment. Of these, compact cities are advocated as the most sustainable and environmentally sound model. Lynch (1981, p. 47) defines urban form as "the spatial pattern of the large, inert, permanent physical objects in a city." Specifically, urban form represents aggregations of repetitive elements as integrated characteristics pertaining to land-use patterns, spatial organizations, and other urban design features, as well as transportation systems and environmental and urban management systems (Handy 1996; Williams et al. 2000). In other words, urban form results from bringing together many urban patterns, which "are made up largely of a limited

number of relatively undifferentiated types of elements that repeat and combine" (Jabareen 2006, p. 39). In concrete terms, the spatial pattern entails similarities and grouped conceptual categories (Lozano 1990) that comprise such components as building densities, block sizes and shapes, street designs, area configurations, spatial scales, public space arrangements, and park layouts (Jabareen 2006). In Achieving Sustainable Urban Form, Williams, Burton and Jenks, (2000, p. 355) conclude that sustainable urban forms are "characterized by compactness (in various forms), mix of uses and interconnected street layouts, supported by strong public transport networks, environmental controls and high standards of urban management."

Sustainable development has undoubtedly inspired a whole generation of urban scholars and practitioners into a quest for the immense opportunities and fascinating possibilities that could be explored by, and the enormous benefits that could be realized from, the planning and development of sustainable urban forms. That is to say, forms for human settlements that will meet the requirements of sustainability and enable the built environment to function in ways that enhance and optimize urban systems in line with the goals of sustainable development in terms of reducing material use, lowering energy consumption, mitigating pollution, and minimizing waste, as well as improving social equity, the quality of life, and well-being. The term "smart sustainable urban form" can be defined as a form for human settlements with all these characteristic features supported with the instrumentation, datafication, and computerization of the built environment on the basis of big data technologies and their applications in order to monitor, understand, analyze, plan, and design such form and to enhance and optimize urban operations, functions, and services in relation to various urban systems and domains in line with the goals of sustainable development.

2.3.5 Smart Sustainable Urbanism: A Data-Driven Approach

Smart sustainable cities relies on constellations of instruments across many scales that are connected through multiple networks augmented with intelligence, which provide and coordinate continuous data regarding the different aspects of urbanity in terms of the flow of decisions about the physical, environmental, social, and economic forms of the city. The evolving research and practice in the field of smart sustainable urbanism tends to focus on harnessing and exploiting the ever–increasing deluge of the data that flood from urban systems and domains, as well as on leveraging the outcome in the transition to sustainable development. Urban systems include built form, urban infrastructure, ecosystem services, human services, and administration and governance. Urban domains involve transport, traffic, mobility, energy, natural environment, land use, healthcare, education, science and innovation, and public safety. Accordingly, urban systems and domains, which overlap in many aspects, span the physical, environmental, social, and economic dimensions of sustainability.

Furthermore, smart sustainable urbanism entails developing urban intelligence functions as an advanced form of decision support on the basis of the useful knowledge that is extracted from large masses of data. Urban intelligence functions represent new conceptions of how smart sustainable cities function and utilize and combine complexity science, urban science, and data science in fashioning powerful new forms of urban simulations models and optimization and prediction methods that can generate urban structures and forms that improve sustainability, efficiency, resilience, and the quality of life (Bibri 2019a, c). In a nutshell, data–driven solutions are of paramount importance to the practice of smart sustainable urbanism in the light of the escalating urbanization. In this field, the operation and organization of urban systems and the coordination of urban domains require not only the use of complex interdisciplinary knowledge, but also the application of advanced technologies, sophisticated approaches, and powerful computational analytics (Batty et al. 2012; Bibri 2019a; Bibri and Krogstie 2018; Bibri, Krogstie and Gouttaya 2020; Bettencourt 2014). In their comprehensive survey on data–driven smart cities, Nikitin et al. (2016) point out that modern cities employ the latest technologies to support sustainable development given rapid urban growth, increasing urban domains, and more complex infrastructure.

The technical features of sustainable urbanism entails the application of advanced ICT as a set of scientific and computational approaches and technical processes. Recent evidence (e.g., Al Nuaimi 2015; Angelidou et al. 2017; Batty et al. 2012; Bettencourt 2014; Bibri 2018a, b, 2019a, b; Bibri and Krogstie 2017b) lends itself to the argument that an integration of the components of sustainable urbanism (i.e., natural ecosystems, physical structures, urban forms, spatial organizations, natural resources, urban infrastructures, socio–economic networks, and ecosystem and human services) with cutting–edge big data technologies can create more sustainable, resilient, livable, and equitable cities. Achieving the goals of urban sustainability through sustainable urban development as a strategic process entails continuously unlocking and exploiting the untapped potential and transformational power of advanced ICT given its disruptive, substantive, and synergetic effects on the forms and practices of sustainable urbanism in the high of the expanding urbanization. Townsend (2013) portrays urban growth and ICT advancement as a form of symbiosis.

One area of advanced ICT that has recently gained increased attention and prevalence is big data analytics. This