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Data-driven smart sustainable cities of the future: An evidence synthesis approach to a comprehensive state-of-the-art literature review

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A R T I C L E I N F O

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A B S T R A C T

Sustainable cities are currently undergoing unprecedented transformative changes in light of the recent paradigm shift in science and technology brought on by big data science and analytics. These marked changes are motivated by the increased need to tackle the problematicity surrounding sustainable cities as quintessential complex systems in terms of their development planning, operational management, and fragmentary design strategies and technology solutions. That is to say, sustainable cities are increasingly embracing and leveraging what smart cities have to offer in terms of big data technologies and their novel applications in an attempt to effectively deal with the complexities they inherently embody and to monitor, evaluate, and improve their performance with respect to sustainability—under what has been termed "data-driven smart sustainable cities." This new area is a significant gap in and of itself—as it is still in its infancy—that this paper seeks to fill together with to what extent the integration of sustainable urbanism and smart urbanism is addressed and what directions and forms it takes. Using a compelling evidence synthesis approach, this paper provides a comprehensive state-of-the-art literature review of the flourishing field of data-driven smart sustainable cities. This study corroborates that big data technologies will change sustainable urbanism in fundamental and irreversible ways, bringing new and innovative ways of monitoring, understanding, analyzing, planning, and managing sustainable cities. It reveals that the evolving development planning approaches and operational management mechanisms enabled by data-driven technologies are of crucial importance to increase and maintain the contribution of sustainable cities to the goals of sustainability in the face of urbanization. However, what smart urbanism entails and the way it functions raises several critical questions, including whether the policy and governance of data-driven smart sustainable cities of the future will become too technocentric and technocratic respectively, but also with regard to other aspects of social and environmental sustainability. Addressing these important contemporary concerns is of equal importance in achieving the desired outcomes of sustainability. This review and critique of the existing work on the prevailing and emerging paradigms of urbanism provides a valuable reference for scholars and practitioners and the necessary material to inform them of the latest developments in the burgeoning field of data-driven smart sustainable cities. In addition, by shedding light on the increasing adoption and uptake of big data technologies in sustainable urbanism, this study seeks to help policymakers and planners assess the pros and cons of smart urbanism when effectuating sustainable urban transformations in the era of big data, as well as to stimulate prospective research and further critical debates on the topic.

1. Introduction

Cities around the world are growing bigger and faster. Urbanization is one of the greatest challenges facing cities of the future. In recent decades, urban growth has been dramatic. For the first time in history, more than half the world's population lives in urban areas [214]. This is expected to rise to 70% by 2050, with an annual population growth of 50–60 million inhabitants, reaching—6.7 billion of this booming population. This implies that 2.4 billion people will be potentially added to the world's population. Already, cities consume more than 75% of the natural resources available globally, including primary energy, raw materials, fossil fuel, water and food. This is estimated to increase by 90 billion tons by 2050 compared to 40 billion tons in 2010 [210]. As an irreversible global trend, urbanization involves a multitude of environmental, social, economic, and spatial conditions, which pose unprecedented challenges to politicians, policy makers, planners, and other practitioners. This fact highlights the importance of shifting paradigms in the way cities work in terms of sustainability. In other words, the increased

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pressure on cities leads to a stronger need to build sustainable cities that last. Designing sustainable cities of the future, educated by the lessons of the past and anticipating the challenges of the future, entails articulating a multi-scalar vision and following key principles—energy, ecology, infrastructure, waste, water, livability, mobility, accessibility, economy, and culture—while responding to major global shifts along the way. These principles are at the core of urban sustainability, which represents an ideal outcome in the sum of all the goals of development planning, on which there is widespread consensus with trade-offs and conflicts when it comes to making decisions.

Sustainable cities have been the leading global paradigm of urbanism (e.g., [1,31,149,221,222]) thanks to the models of sustainable urban form proposed as new frameworks for redesigning and restructuring urban places for making urban living more sustainable. Compact cities and eco-cities are the most advocated models of sustainable urban form and the central paradigms of sustainable urbanism. They continue to strive towards reaching the required level of sustainability by enabling the built environment to function in ways that reduce material use, lower energy consumption, mitigate pollution, and minimize waste, as well as improve social equity, human well–being, and the quality of life (see, e.g., [35,40,95,109,117,124,159,165,174,202]). The subject of "sustainable cities" remains endlessly appealing given the numerous actors as well as institutions involved in the academic and practical aspects of the endeavor, conducting research, developing new approaches, enhancing strategies, devising political mechanisms, formulating regulatory frameworks, facilitating the coordination between a range of stakeholders, and allocating material and social resources. This is primarily to promote and spur innovation and monitor and maintain progress towards achieving the status of sustainable cities. Indeed, in order to continuously deliver the benefits of sustainable cities and to improve their performance in the longer term, innovative solutions are and will be needed along the way.

Transformative processes within sustainable cities have been in focus for quite some time now. The motivation for achieving the Sustainable Development Goal (SGD) 11 of the United Nations' 2030 Agenda—Sustainable Cities and Communities in terms of making cities sustainable, resilient, inclusive, and safe [212] has increased the need to understand, plan, and manage sustainable cities in new and innovative ways. These are increasingly based on more advanced forms of ICT, especially big data technologies. The United Nations's 2030 Agenda regards advanced ICT as a means to promote socio–economic development, restore 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 [213]. This relates to the multifaceted potential of smart cities with respect to the role of big data technologies and their novel applications in strategic sustainable development. The explosive growth of urban data, coupled with their analytical power, opens up for new opportunities for innovation in sustainable cities. This in turn means finding and applying more effective ways of translating sustainability into the physical, spatial, environmental, economic, and social forms of the city. Regardless, cities are increasingly being seen through big data [203]. In a nutshell, new circumstances require new responses.

The conscious push for sustainable cities to become smarter and thus more sustainable in the era of big data is due to the problematicity surrounding their development planning approaches, operational management mechanisms, and fragmentary design strategies and environmental technology solutions [39]. This has a clear bearing on their performance with respect to the contribution to the goals of sustainability. This situation is compounded by the escalating trend of urbanisation and its negative consequences, and also continuously exacerbated by the unpredictability of climate change, economic crisis, pandemics, and demographic changes. In order to deal with these problems and challenges, advanced forms of ICT are required. New and emerging technologies offer great potentials and opportunities for innovation that can produce a high quality of life and fuel sustainable economic development together with a wise management of natural resources. They are also of crucial importance to the understanding of sustainable cities as complex systems—dynamically changing environments and self-organizing social networks embedded in space and enabled by various types of infrastructures, activities, and services.

Therefore, it is necessary to develop and apply more sophisticated approaches and innovative solutions to the development planning and operational management of sustainable cities. In response, sustainable cities are increasingly embracing and leveraging what smart cities have to offer in terms of big data technologies and their novel applications in an attempt to effectively deal with the complexities they inherently embody and to monitor, evaluate, and improve their performance with respect to sustainability—under what has been termed "data-driven smart sustainable cities." In fact, the real challenge for the future lies in moving genuinely past the assumption that there are only two contrasting, mutually exclusive realities—either sustainable cities or smart cities. An 'either/or' approach will hamper progress towards urban sustainability, as the huge challenges facing sustainable cities within many of their administration spheres (transport, traffic, mobility, energy, environment, waste, healthcare, public safety, governance, etc.) require an integrated approach to urbanism.

Data-driven smart sustainable cities as a new area of research is a significant gap in itself—as it is still in its infancy and is largely characterized by visions—together with to what extent the scope of the integration of sustainable cities and smart cities is addressed in the literature. Using a compelling evidence synthesis approach, this paper provides a comprehensive state-of-the-art literature review of the flourishing field of data-driven smart sustainable cities, addressing six questions, namely:

- Q1: What urbanism paradigms underpin data-driven smart sustainable cities and how do they relate to or complement each other in the context of sustainability?
- Q2: What are the key deficiencies and shortcomings associated with compact cities and eco-cities and how can they be addressed and overcome?
- Q3: What are the major problems, issues, and challenges related to sustainable cities?
- Q4: What societal trends interplay with sustainable cities and are behind data-driven smart sustainable cities?
- Q5: What is the innovative role of the applied data-driven technology solutions of smart cities in enhancing and maintaining the performance of sustainable cities?
- Q6: What are the potential risks and negative implications of smart urbanism and to what extent do they affect data-driven smart sustainable urbanism with respect to sustainability?

The added value of this review resides in its topicality, thoroughness, substantive nature, as well as original contribution in the form of novel insights as a result of synthesizing a large body of literature characterized by various disciplinarities.

The remainder of this paper unfolds as follows: Section 2 details and justifies the literature review methodology. Section 3 describes and discusses the key paradigms of urbanism underpinning data-driven smart sustainable cities. Section 4 provides a thorough analysis, evaluation, synthesis, and discussion of the emerging phenomenon of data-driven smart sustainable cities. Section 5 identifies and enumerates the relevant topics associated with the key knowledge gaps in the area of data-driven smart sustainable cities. Finally, this paper concludes, in Section 6, by providing a summary of the key findings, highlighting the main contributions, and suggesting some future research directions.

2. Methodology

2.1. Interdisciplinary and transdisciplinary perspectives

Research review has long been one of the most important scholarly activities in all academic disciplines or branches of science. This literature review analyzes, evaluates, synthesizes, and discusses a large body of research done on the burgeoning field of data-driven smart sustainable cities in terms of the underlying models of urbanism and their amalgamation for the purpose of advancing the goals of sustainability. In doing so, it draws on a number of city-academic or scientific disciplines and their integration and fusion, as well as on practical insights from numerous single and multiple case studies.

Interdisciplinarity and transdisciplinarity have become a widespread mantra for research within diverse fields, accompanied by a growing body of scholarly publications. The research field of data-driven smart sustainable cities is profoundly interdisciplinary and transdisciplinary in nature. It operates out of the understanding that advances in knowledge necessitate pursuing multifaceted questions that can only be resolved from the vantage point of interdisciplinarity and transdisciplinarity. This in turn implies that the research problems within this field are inherently too complex and dynamic to be addressed by single disciplines. This is clearly reflected in the literature on sustainable cities, smart cities, and smart sustainable cities in the era of big data.

Accordingly, the interdisciplinary and transdisciplinary approaches to scholarly research apply by extension to the review of this literature. The former insists on mixing disciplines, and crosses boundaries between different disciplines to create new perspectives and insights on the basis of interactional knowledge beyond these disciplines. Its strength lies in the ability of interlinking different analyzes using insights and methods from different disciplines in parallel and spilling over disciplinary boundaries. The latter insists on fusing different disciplines and thus using insights and methods from these disciplines in conjunction—with a result that exceeds the simple sum of each of them. Transdiciplinarity concerns that which is at once between, across, and beyond single disciplines.

2.2. Approaches and objectives: a best-evidence synthesis and state-of the art review

Reviews are generally divided in different categories, each with own qualities and perspectives on reviewing a topic, namely systematic review, best-evidence synthesis, narrative review, meta-analysis, scoping review, umbrella review, and rapid review. As a rigorous approach, a systematic review identifies, evaluates, and synthesizes research evidence from individual studies based on a strict protocol. It minimizes the risk of bias and enables a balanced, impartial inclusion a measure of high quality by ensuring all possible and relevant research bases have been considered and a valid analysis of the original studies has been made [60]. A systematic review is best suitable for focused topics [52]. This is not the case for the topic of data-driven smart sustainable cities, which involves multifaceted questions and different research strands. As to the narrative approach to literature review, which is applied in this study, it is of a wide scope and non-standardized nature and does not follow an established procedure. A narrative review summarizes different primary studies from which conclusions may be qualitatively drawn into a holistic interpretation contributed by the reviewers' own experiences, existing theories, and models [126]. It also proposes to comprehend the diversities and pluralities of understanding around scholarly research [112]. Narrative reviews are best suitable for comprehensive topics [52].

As regards the best-evidence synthesis approach to literature review, which complements the narrative approach in this study, it draws on a wide range of evidence and explores the impact of context. As such, it brings together all relevant information on a research topic, which can be useful to identify gaps in knowledge, establish an evidence base for best-practice guidance, or help inform policymakers and practitioners. It is argued that it offers an alternative to a narrative review, giving attention to substantive issues of a narrative point of view, adding a rational for study-selection and effectiveness of treatment, and emphasizing the importance of well-justified inclusion criteria. By providing the reader enough information about the primary research, they must be able to reach independent conclusions, as "far more information is extracted from a large literature by clearly describing the best evidence on a topic than by using limited journal space to describe statistical analyses of the entire …substantively diverse literature" ([193], p. 7). Overall, this study intends to demonstrate the usefulness of combining the two substantive categories of literature review.

Generally, there are different objectives of literature review, including methodological, theoretical, thematic, and state of the art. This literature review is concerned with the state-of-the-art and thematic objectives. The former considers mainly the most current research and summarizes emerging research priorities and academic trends in the field. It provides a critical survey of the extensive literature produced in the past decade or so, a synthesis of current thinking in the field, and also offers new perspectives. The latter describes particular areas of the literature (e.g., particular models of urbanism), where the intent of the outcome is to identify weaknesses and disseminate the path towards improvements. It provides an in-depth examination of the principles underlying the phenomenon under study through the evaluation of its objectives.

2.3. Hierarchical search strategy and scholarly sources

A literature search is the process of querying quality scholarly literature databases to gather the research publications pertaining to the topic under review. A search strategy was used, covering several electronic search databases, including Scopus, ScienceDirect, SpringerLink, and SageJournals, in addition to Google Scholar. The main contributions came from the leading journal articles. The hierarchical search approach adopted involves:

- 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 targeted 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.

2.4. Selection criteria: inclusion and exclusion

To find out what is known about the burgeoning field of data-driven smart sustainable cities, the above search approach was adopted with the objective to identify the relevant studies addressing the various strands of research within this field that cover the six questions to be answered. Accordingly, the preliminary selection of the available material was done in accordance with the problems under study. In this respect, it is feasible to refine and narrow down the scope of reading, although there may seem to be a number of information sources that appear to be pertinent to the topic on focus. With that in mind, for a document to be considered as to its potential to provide any information of relevance, it should relate to one of the conceptual subjects or thematic categories specified in regard to the questions being addressed. These represent more or less the headings of the sections and subsections of this paper. The focus was on the documents that provided definitive primary information, typically from the following scholarly perspectives:

- Crossdisciplinary: viewing one discipline or field from the perspective of another
- Interdisciplinary: integrating knowledge and methods from different disciplines or fields based a synthesis of approaches
- Transdisciplinary: creating a unity of intellectual frameworks beyond the disciplinary boundaries

The main purpose was to accumulate a relatively complete body of relevant literature. On the whole, scoring the documents to be selected was based on the inclusion of the problems being addressed, though to varying degrees with respect to the conceptual subjects and thematic categories decided on. The latter was meant to emphasize the quintessential aspects of data-driven smart sustainable cities. Conversely, the documents excluded were those that did not meet the specific criteria as regards their relevance to the problems being addressed. Nonetheless, a few of these documents provided some insights related to the paradigms of urbanism underpinning data-driven smart sustainable cities as an integrated model. Furthermore, the abstracts were reviewed to assess their relevance to the topic on focus, as well as to ensure a reliable application of the inclusion and exclusion criteria. Inclusionary discrepancies were resolved by the re–review of the abstracts. The process allowed to further refine and narrow down the scope of reading.

The keywords searched for included “smart cities,” “compact cities,” “eco-cities,” “data-driven cities,” “data-driven smart cities,” “data-driven smart sustainable cities,” “smart eco-cities,” “smart urbanism,” “scientific urbanism,” “compact urbanism,” “eco-urbanism,” “data-driven urbanism AND sustainability,” “data-driven smart sustainable urbanism,” “urban planning AND big data analytics,” “urban management AND big data analytics,” “urban intelligence AND sustainability,” “urban computing AND sustainability,” and “smart urban governance” These keywords were used to search against such categories as the articles’ keywords, title, and abstract to produce some initial insights. Due to the limitations associated with relying on the keyword approach, backward literature search (backward authors and backward references) and forward literature search (forward authors and forward references) were occasionally used to enhance the search approach [220].

2.5. Purposes and organisational approaches

The literature review is typically performed for various purposes. This depends on whether it is motivated by, or an integral part of, a research study and thus its scope or area of focus. This explains the extent to which the research area will be explored in the study, which basically means defining what the study covers and what it focuses on. This literature review is for publication and thus carried out in order to:

- describe and discuss the conceptual foundation of data-driven smart sustainable cities as an integrated model of urbanism;
- analyze, evaluate, and synthesize the existing knowledge in the field of data-driven smart sustainable cities;
- highlight the strengths, weaknesses, and contradictions of the existing knowledge in the field, thereby providing a critique of the research that has been carried out in the field;
- discuss the identified strengths and weaknesses with respect to sustainability and data-driven technologies and their relationships;
- identify the opportunities, potentials, and prospects offered by data-driven technologies in terms of improving and advance urban sustainability; and
- identify the key relationships between the key relevant studies addressing the different strands of the topic on focus by comparing, linking, and leveraging their results.

This 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 data-driven smart sustainable cities. The analysis, evaluation, 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 perspective with respect to the selected studies. In so doing, the focus is on the major publications considered as significant in the field.

3. Sustainable urbanism and smart urbanism paradigms

3.1. Sustainable cities

Despite the fact that the discourse of sustainable cities is now mature and powerful, precise conceptualisations are still rare and often contested. Notwithstanding the near universal recognition of sustainable cities being a desirable vision or goal of policy, there is less certainty about what this might mean in practice [222]. Sustainable cities are so complex and intangible that the notion of what the concept means is constructed in a variety of ways within different city-related disciplines (e.g., engineering, social science, and computing). Consequently, there are multiple views on what a sustainable city should be or look like and thus various ways of conceptualizing it. Broadly, a sustainable city can be understood as an approach to practically applying the knowledge about sustainability to the planning and design of existing and new cities. It represents an approach to sustainable urban development, which is a strategic process to achieve the long–term goals of urban sustainability. Accordingly, it needs to balance between the environmental, economic, and social dimensions of sustainability (Fig. 1).

As an integrated process of change, a sustainable city strives to maximize the efficiency of energy and material use, minimize waste generation, support renewable energy production and consumption, promote carbon–neutrality, reduce pollution, provide efficient and sustainable transport, emphasize compactness, support design scalability and spatial proximity, preserve ecosystems and green space, and to promote livability and community–oriented human environments. In a nutshell, a sustainable city must meet the needs of the population without undermining the ability of future generations to meet their own needs.

There are different approaches to sustainable cities, which tend to be identified as models of sustainable urban form. These include compact cities, eco–cities, new urbanism, urban containment [104], landscape ecological urbanism (landscape architecture and urban ecology [135,198], and so on. Compact cities and eco-cities are the central paradigms of sustainable urbanism and the most prevalent and advocated models of sustainable urban form. Compact cities and eco-cities are the central paradigms of sustainable urbanism and the most prevalent and advocated models of sustainable urban form [24]. Williams, Burton and Jenks [[223], 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.” This characterization implies more or less a combination of the dimensions of compact cities and eco–cities. However, management tends to dominate within the eco–city, unlike the compact city where design is at the core of compaction strategies. That is to say, the eco-city is about how the urban landscape is organized and steered rather than the spatial pattern of the characteristic physical objects in the city. Still, these two models of sustainable urban form share several concepts, ideas, and visions.

3.2. Compact cities

There is no definite definition of the compact city in the literature, despite the general consensus on its common dimensions. To Burton [47], the so-called compact city is taken to mean “a relatively high–density, mixed–use city, based on an efficient public transport system and dimensions that encourage walking and cycling.” According to other views (e.g., [106,107,223]), the compact city is characterized by high–density and mixed land use with no sprawl. Dantzig and Saaty [58] provide an explanation of the densification characteristics based on three elements: the urban form, the space, and the social functions (Table 1). For a detailed discussion of the definitional issues of the compact city, the interested reader might be directed to Bibri [25].

While there seems to be a general consensus on the main dimensions of the compact city—compactness, density, mixed-land use,

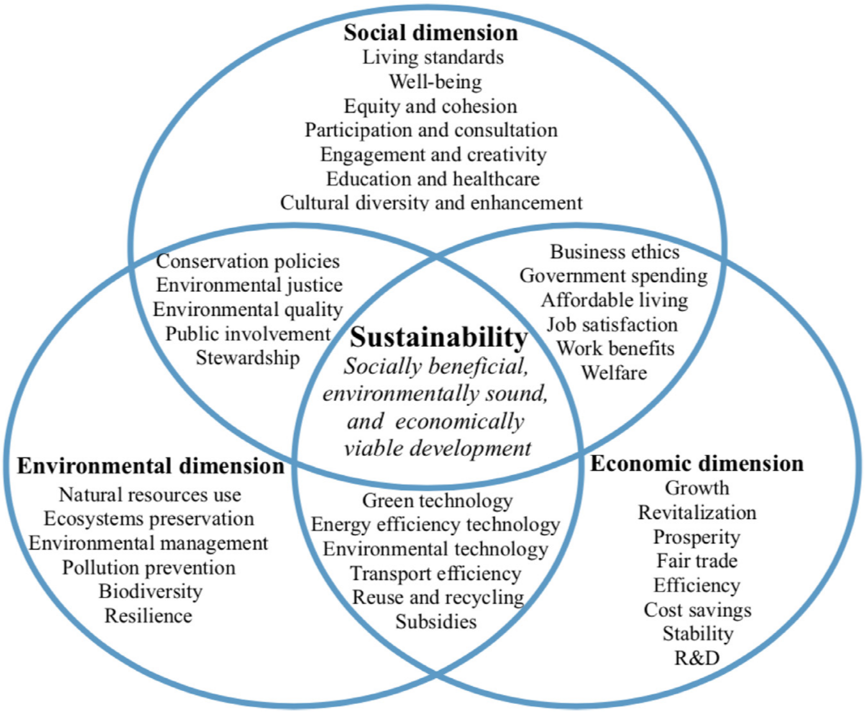

Fig. 1. A framework for balancing the three dimensions of sustainability.

Table 1
Densification characteristics.

Urban form features	Spatial features	Social functions
• High dense settlements • Less dependence on automobile • Clear boundary from surrounding areas	• Mixed land use • Diversity of life • Clear identity	• Social fairness • Self-sufficiency of daily life • Independence of government

diversity, sustainable transportation, and green open space, there still are great differences between cities in regard to their built form given their specificities. These relate to their physical, geographical, socio–political, economic, and historical aspects. In fact, every compact city has “unique individuality, own life, and physiognomy,” and it is a “complex individual” [177] entangling individuals, communities, and neighbourhoods and constituting particularities of urban fabrics. An urban fabric denotes the physical characteristics of urban areas in terms of components, materials, buildings, spatial patterns, scales, streetscapes, infrastructure, networks, and functions, as well as socio-cultural, ecological, economic, and organizational structures. Table 2 presents a set of varied characteristics derived from studies where compaction strategies are approached from a variety of perspectives ([15,40,65,113,132,143,160,195,211,216]) generating some specificities.

The compact city is the most advocated model of sustainable urban form due to its ability to produce the benefits of sustainability as to its tripartite composition, though to varying degrees. When strategically planned and well–designed, the compact city becomes able to support the balancing of the three goals of sustainability (e.g., [47,95,109,165]), supported specially with applied technology solutions for environmental and social sustainability [39].

3.3. Eco-cities

The idea of the eco–city is widely varied in conceptualization and operationalization. Consequently, there are multiple definitions of the eco–city, depending on the context where it is embedded in the form of urban projects and initiatives in terms of the practices and strategies adopted to achieve the goals of the eco-city. Roseland [180] argues that there is no single accepted definition of the eco–city, but more a collection of ideas about concepts. Joss [115] substantiates the conceptual diversity and plurality of the initiatives and projects using the term across the globe. Bibri [24] provides a detailed discussion of the definitional issues of the eco-city. Rapoport [174] traces the evolution of the eco-city as a concept and an urban planning model over the last 40 years, outlining the various definitions, applications, and critiques of the term. However, there is some consensus on the basic features of an eco-city among available definitions (see Table 3).

The concept of the eco-city has also been used to describe a wide range of urban projects and initiatives, mostly large-scale new districts, encapsulating a diversity of conceptualizations and pulling together an ensemble of normative and prescriptive principles supported by various policies about how to develop and design sustainable urban areas. An eco-city is based on three analytical categories: (1) a development on a substantial scale, (2) occurring across multiple domains, and (3) supported by policy processes [116]. Kenworthy [124] argues that the eco-city should incorporate ten key dimensions, with sustainable urban form and transport at the core of the model. Based on a recent case study, Bibri and Krogstie [38] distil the main design strategies and technology solutions of the eco-city for achieving the environmental goals of sustainability, namely:

- Renewable energy technology
- Energy efficiency technology
- Sustainable waste management
- Passive solar houses
- Net-zero and low-energy buildings
- Sustainable materials
- Smart urban metabolism

Table 2
Specific characteristics of compact cities.

- Adequate space for streets
- Efficient street network/high degrees of street connectivity, including sidewalks and bicycle lanes
- Limited land use specialization
- Built environment characteristics
- Urban layout
- Pedestrian access
- High degree of accessibility: local/regional
- Street design and circulation system
- Spatial distribution of population
- Spatial distribution of trips
- Population by distance to center of gravity
- High residential and employment density
- High density of built objects in both designed and emergent urban areas
- Diverse scales of built objects
- Distribution of building footprints with frequent larger buildings
- High–density hand in hand with multidimensional mixed land use
- Fine grain of land uses (proximity of varied uses and small relative size of land parcels)
- Increased social and economic interactions
- Contiguous development (some parcels may be vacant or abandoned or surface parking)
- High degree of impervious surface coverage
- Unitary control of planning of land development, or closely coordinated control

Table 3
Some definitions of the eco-city.

An eco-city is "an urban environmental system in which input (of resources) and output (of waste) are minimized" [178].
"The eco-city is an umbrella metaphor that encompasses a wide range of urban–ecological proposals that aim to achieve urban sustainability. These approaches propose a wide range of environmental, social, and institutional policies that are directed to managing urban spaces to achieve sustainability" Jabareen [[104], pp. 46-47].
"An eco–city is a human settlement which emphasizes the self–sustaining resilient structure and function of natural environment and ecosystems. It seeks to provide a healthy and livable human environment without consuming more renewable resources than it replaces" (([25], p. 7).
An eco-city is "a human settlement that enables its residents to live a good quality of life while using minimal natural resources" [68].

Table 4
Three types of eco-city models.

Type 1	Type 2	Type 3
• Eco-village	• Eco–City	• Symbiotic City
• Solar City	• Eco–District	• Carbon Neutral City
• Solar Village	• Environmental City	• Zero Energy City
• Cohousing	• Green City	• Zero Carbon City
• Sustainable Housing	• Garden City	• Net Zero Carbon Community
	• Sustainable Neighborhood	• Low Carbon City
	• Sustainable Community	• Ubiquitous Eco–City
	• Sustainable Urban Living	• Smart Eco–City
	• Living Machines	• Data-Driven Smart Eco-City

- Sustainable transportation
- Mixed-land use

The eco-city focuses more on the environmental dimension of sustainability in terms of the natural environment and ecosystems than on the economic and social dimensions of sustainability (e.g., [99,158,175]). While the natural environment has been a common concern throughout the history of urban planning [224], eco-cities bring this concern to the forefront of the planning process. Based on an extensive literature review conducted by Bibri [24], there are many models of the eco–city, which can be caterogarized into three types: Type 1 emphasizes passive solar design, type 2 combines passive solar design and greening, and type 3 focuses on green energy technologies and/or smart energy and environmental technologies (Table 4). The latter relates to the concept of the smart eco-city which captures the recent trend of future-oriented urban development schemes that display both green and smart ambitions.

3.4. Smart cities

It is difficult to identify the common trends of smart cities at the global level. The smart city concept is still without a universally agreed definition, as there seems to be neither a predetermined template for, nor a one-size-fits-all approach to its definition. As a consequence, there still is a lack of conceptual clarity around the smart city concept, or inconsistent understanding of what it means, despite the popularity of smart cities. The concept having different connotations and being approached from a variety of perspectives is clearly manifested in the various ways in which many governments across the globe set initiatives or implement projects to enable their cities to badge or regenerate themselves as smart, or to plan to become smart. As a result, a large number and variety of definitions have been suggested, with a plethora of scopes, which has led to confusion amongst urban policymakers, working on establishing public policies to enable the transition to smarter cities [2]. Toli and Murtagh [206] offer a comprehensive literature review where they identify 43 smart city definitions (derived from academic, industrial, and institutional literature) assessed according to the three dimensions of sustainability that they consider and the priority in which they accord the concept of sustainability. Table 5 presents a selected set of additional definitions of the smart city, adding further emphases to its concept.

Furthermore, based on a survey on smart cities [31], there are two main approaches to the smart city: (1) the technology–oriented approach, i.e., infrastructures, architectures, platforms, systems, ap-

Table 5
Definitions of smart cities.

"Connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city… A city striving to make itself "smarter" (more efficient, sustainable, equitable, and livable" ([51], p. 2292).
"A smart city is a very broad concept, which includes not only physical infrastructure but also human and social factor" ([162], p. 27).
The "smartness" of a city is a "certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth" ([233], p. 218).
"Smart cities is a term…that describe cities that, on the one hand, are increasingly composed of and monitored by pervasive and ubiquitous computing and, on the other, whose economy and governance is being driven by innovation, creativity and entrepreneurship, enacted by smart people" ([127], p. 1).
"A smart city is…a city which invests in ICT enhanced governance and participatory processes to define appropriate public service and transportation investments that can ensure sustainable socio–economic development, enhanced quality–of–life, and intelligent management of natural resources" ([5], p 3).
"As presently understood, a smart city is one that strategically uses networked infrastructure and associated big data and data analytics to produce a: *smart economy…*; *smart government…*; *smart mobility…*; *smart environments…*; *smart living…*; and *smart people…*" ([128], p. 8).
"A smart city can be described as a city that is increasingly composed of, and monitored and operated by, various forms of pervasive computing, as well as whose planning and governance are driven by innovation as enacted by various stakeholders that capitalise on and exploit cutting–edge technologies in their endeavors and practices…. A smart city can also be taken to mean a technologically and data–analytically advanced city that is able to monitor and understand its environment and citizens and explore and analyze various forms of data to generate useful knowledge in the form of applied intelligence that can immediately be used to solve different problems, or to make changes to improve the quality of life and the health of the city" ([20], p. 11).
"Smart city is a concept of urban transformation that should aim to achieve a more environmentally sustainable city with a higher quality of life, that offers opportunities for economic growth for all of its citizens, but with respect to the particularities of each locality and its existing inhabitants. This transformation is currently enabled by various types of technologies…that are embedded into the city's infrastructure system " ([206], p. 8)

plications, and models and (2) the people–oriented approach, i.e., stakeholders, citizens, knowledge, services, and related data. Also, Nam and Pardo [161] conceptualize the smart city with the dimensions of technology, people, and institutions. To gain a broad understanding of the smart city, the interested reader might be directed to Song et al. [196] who provide a detailed overview of the foundations, principles, and applications of smart cities.

Sustainability has recently become one of the strategic goals of smart cities. Therefore, it is of relevance to highlight some of the work that focuses on the role of ICT as well as human and social capital in smart cities in relation to sustainability (e.g., [8,20,73,75,86,97,137,154,161,162,209]). This strand of research is concerned with smart cities as urban innovations that are aimed at integrating, harnessing, and advancing physical and social infrastructures for environmental protection, economic regeneration, and enhanced public services and well-being. One of the most cited definitions of the smart city concept, advanced by Caragliu, Del Bo and Nijkamp [[51], p. 6], states that a city is smart "when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance." As an extension of this definition, Pérez–Martínez et al. (2013, cited in [1]) describe smart cities as "cities strongly founded on ICT that invest in human and social capital to improve the quality of life of their citizens by fostering economic growth, participatory governance, wise management of resources, sustainability, and efficient mobility, whilst they guarantee the privacy and security of the citizens." In this line of thinking, Batty et al. [[12], pp. 481–482] describe smart cities as cities in which "intelligence functions...are able to integrate and synthesize…these [urban] data to some purpose, ways of improving the efficiency, equity, sustainability, and quality of life in cities." Stübinger and Schneider [200] provide a systematic literature review on the area of smart city using a data-driven approach. The authors reveal that smart sustainability will come to the fore in the next years—this fact confirms the current trend as minimizing the required input of energy, water, waste, heat output, and air pollution is becoming increasingly important.

There are a number of approaches to smart cities (see [20] for a detailed review), as well as to smarter cities, including smart cities of the future (e.g., [12]), ubiquitous cities (e.g., [189]), ambient cities (e.g., [42]), sentient cities (e.g., [205]), real-time cities (e.g., [127]), data-driven cities (e.g., [163]), and so on. The latter approach is one of the recent faces of smarter cities.

All in all, a smart city is a city that focuses on developing and implementing applied innovative technology solutions in all of its systems and domains, and consequently perform in forward–looking and participatory ways to enhance the effects of its strategies on the basis of the combination of the endowments and activities of independent and aware citizens together with other stakeholders (organisations, institutions, industries, enterprises, and communities). This is to ensure and maintain socio–economic development, the quality of life, the efficiency of service delivery, the wise management of natural resources, and the optimized operation of infrastructures and facilities—ideally in line with the goals of sustainability. Indeed, these goals are not viewed equally in the diverse sustainability oriented definitions of the smart city.

3.5. Data-driven smart cities

The data-driven city is one of the recent faces of smart cities. As such, it represents an emerging paradigm of smart urbanism: data-driven smart cities. It is too often associated with "smarterness" under what is labeled "data-driven smart cities" (e.g., [36,66,136,155,188]). This is due to the fact that big data technology is an advanced form of ICT, which is an enabler of all approaches to smarter cities, such as ambient city, sentient city, ubiquitous city, and real-time city.

There is no definite definition or a single conceptual unit of a data-driven city, nor is there an agreed industry or academic description thereof. In a broader sense, the data-driven city is a city that implements datafication for enhancing and optimizing its operations, functions, services, strategies, and policies to some purpose. The concept employs big data technologies to bring about changes to city life, which are for the better. The phenomenon of the data-driven city has materialized as a result of the emergence of big data science and computing and the wider adoption of the underlying technologies, the explosive growth of urban data, and the transformation of urban landscape in the light of urbanization. These developments can be used in a range of proposals for a conceptual framework for the data-driven city. For example, Nikitin et al. [163] use a notion which embraces the basic elements used in the management of the data-driven city, namely data, processing technologies, and government agencies in regard to such domains as transport, utilities, environment, healthcare, education, citizen participation, and security. Accordingly, the authors describe the data-driven city as a city that is characterized by the ability of city management agencies to use technologies for data generation, processing, and analysis aimed at the adoption of solutions for improving the living standards of citizens thanks to the development of social, economic and ecological areas of urban environment. Overall, the data-driven city is digitally instrumented, datafied, and networked for enabling large-scale computation to enhance decision making processes across various urban domains for enhancing and optimizing operational management and planning development in line with the environmental, economic, and social aspects of sustainability.

The assessment of the effects from the implementation of the data-driven city is one of the key issues when implementing applied solutions in the city management. These effects can be categorized into three types, namely [163]:

- The direct effect of an initiative is an operative or economic effect of a particular project obtained directly by the project participants.
- The synergistic effect of a range of initiatives is an effect provided by a set of data-driven solutions and influencing a particular area of city life.
- The general effect on society and economics is a cumulate effect on the living standards of citizens influencing directly the participants and users of the data-driven solutions.

3.6. Smart sustainable cities

The concept of the smart sustainable city has emerged as a result of three important global shifts at play today across the world, namely the diffusion of sustainability, the spread of urbanization, and the rise of ICT. As echoed by Höjer and Wangel [96], the interlinked development of sustainability, urbanization, and ICT has recently converged under what is labeled "smart sustainable cities." This currently leading paradigm of urbanism has materialized around the mid-2010s [31]. It revolves around the idea of leveraging the convergence, ubiquity, and potential of ICT of pervasive computing in the transition towards sustainability in an increasingly urbanized world. Therefore, it has gained traction and prevalence worldwide as a promising response to the imminent challenges of sustainability and urbanization. It is being embraced as an academic pursuit and societal strategy in different parts of the world, evolving into a scholarly and realist enterprise, not least within the ecologically and technologically advanced nations. In a nutshell, the concept of smart sustainable cities has become the center of attention among research institutes, universities, governments, policymakers, businesses, industries, consultancies, and communities.

The term "smart sustainable city," is used to describe a city that is supported by the pervasive presence and massive use of advanced ICT, which, in connection with various urban systems and domains and how these are complexly integrated and intricately coordinated respectively, enables the city to control available resources safely, sustainably, and efficiently to improve economic and societal outcomes. The integration of smart cities and sustainable cities has been less explored and underdeveloped, both conceptually and empirically due to the multiplicity and diversity of the existing definitions of smart cities and sustainable cities. ITU [102,103] defines a smart sustainable city as "an innovative city that uses ICT and other means to improve the quality of life, efficiency of urban operation and services, and competitiveness while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects." Another close definition put forth by Höjer and Wangel [[96], p. 10] states: "a smart sustainable city is a city that meets the needs of its present inhabitants without compromising the ability for other people or future generations to meet their needs, and thus, does not exceed local or planetary environmental limitations, and where this is supported by ICT." This entails unlocking and exploiting the potential of ICT of pervasive computing as an enabling, integrative, and constitutive technology with embodied transformational, substantive, and disruptive effects for producing the environmental, social, and economic benefits of sustainability. From a socio-technical perspective, Bibri [[17], p. 299] defines a smart sustainable city "as a social fabric and web made of a complex set of networks of relations between various synergistic clusters of urban entities that, in taking a holistic perspective, converge on a common approach to developing and implementing smart technologies to adopt and disseminate the innovative applied solutions and sophisticated approaches that improve and advance sustainability." In view of that, smart sustainable cities are inherently intricate through the very technologies being used to monitor, understand, analyze, and plan their infrastructures and systems to improve their contribution to sustainability in the face of the escalating rate and scale of urbanization.

There are many approaches to smart sustainable cities apart from the data-driven approach and its integration with the compact and ecological approaches, which is the main focus of this paper. These approaches depend on the strategies that the cities badging or regenerating themselves as smart sustainable prioritize with respect to applied technology solutions and sustainability dimensions based on the kind of challenges they deal with (see, e.g., [4,18,133,164,171,191]). However, there is a gap in knowledge in relation to the holistic assessment of the smartness and sustainability levels of a smart sustainable city. Therefore, Al-Nasrawi, Adams, and El-Zaart [4] propose a new multidimensional model capturing the smartness of a city while sensitizing it with its context peculiarities.

3.7. Data-driven smart sustainable cities

In the context of this study, smart sustainable cities as an integrated and holistic model of urbanism is approached from the perspective of combining and integrating the strengths of sustainable cities and smart cities and harnessing the synergies of their strategies and solutions in ways that enable sustainable cities to improve and advance their contribution to the goals of sustainability on the basis of the innovative data-driven technologies and solutions offered by smart cities. Bibri and Krgostie [39] develop a novel model for data-driven smart sustainable cities of the future in the form of a strategic planning process of transformative change towards sustainability. The authors specify the set of targets that need to be reached in order to attain the status of data-driven smart sustainable cities of the future (Table 6). These targets are based on the synergistic integration of the strategies and solutions of the prevailing paradigms of sustainable urbanism and the emerging paradigms of smart urbanism. The essence of the aggregate model lies in providing the needed tools, techniques, methods, systems, platforms, and infrastructures enabled by the core enabling and driving technologies of the IoT and big data analytics for sustainable cities to have a more measurable, targeted and harmonized contribution to sustainability.

A data–driven smart sustainable city is a city that is increasingly composed of and monitored by ICT of pervasive and ubiquitous computing and thus has the ability to use the IoT and big data technologies to generate, process, analyze, and harness urban data for the purpose of creating deeper insights that can be leveraged to make decisions that accurately address the problems, issues, and challenges related to sustainability and urbanization. The emerging data-driven solutions can be adopted by city management agencies and city planning and policy centers to improve sustainability, efficiency, resilience, equity, and the quality of life. Underlying data-driven smart sustainable cities is a number of platforms and centers associated with technical and institutional competences and practices (see [27] for a descriptive account), namely:

- Horizontal information systems
- Operations centers and dashboards
- Research and innovation centers
- Educational centers and training programs
- Strategic planning and policy centers

These competences relate to the degree of the readiness of the city to introduce data-driven technology in its management as well as to the degree of the implementation of applied technology solutions in its management. The degree of readiness is characterized by the availability and development level of the technological infrastructure and competencies needed to generate, transmit, analyze, and visualize data. The degree of implementation demonstrates the extensive use of the applied technology solutions in city operational management and development planning in relation to the different areas of sustainability.

Table 6
The core compact, ecological, and technological targets of data-driven smart sustainable cities.

- Increased compactness of urban space
- High density and diversity of buildings
- Multidimensional mixed uses: social mix, physical land use mix, economic mix, and temporal mix
- Prioritized sustainable transportation and its integration with smart transportation
- Multifunctional green infrastructure for ecosystem services and biodiversity
- Balanced mixture of low-energy, energy-efficient, and passive buildings
- Large–scale net–zero and locally produced solar energy houses
- Sustainable energy system and its integration with smart energy system
- Sustainable waste system and its integration with smart waste system
- High degree of the readiness of the city to the integration of advanced technology in its management:
  - High availability and development level of the infrastructure and big data analytics competencies required for the functioning of the city
  - New and extensive sources of data and a high level of support for open and standard data
- High degree of the implementation of applied technology solutions for the city management:
  - High level of the development of applied data-driven solutions for the city operational management and development planning related to the various areas of sustainability
  - Established data-oriented competences pertaining to research, innovation, strategic planning and policy, education, and professional training.

4. Analysis, evaluation, synthesis, and discussion

4.1. Compact cities and eco-cities

4.1.1. Commonalities, shortcomings, deficiencies, and opportunities

Sustainable development has undoubtedly inspired a whole generation of urban scholars and practitioners into a quest for the tremendous opportunities that could be explored by, and the enormous benefits that could be realized from, the planning and design of the existing models of sustainable urban forms, notably compact cities and eco-cities. Sustainable urban development is seen as one of the keys towards unlocking the quest for a sustainable society. Therefore, it is promoted by global, national, and local policies alike as the most preferred response to the challenges of sustainable development. Compact cities and eco-cities are the central paradigms of sustainable urban development and the most prevalent and advocated models of sustainable cities. Numerous recent national and international policy reports and papers state that these two models contribute, though to varying degrees, to resource efficiency and reliability, environmental protection, socio-economic development, social cohesion and inclusion, quality of life and well-being, and cultural enhancement. It is argued that the compact city model is able to contribute to and support the balancing of the three goals of sustainability (e.g., [40,47,95,108,109,165]), and that the eco–city model is able to achieve the goals of environmental sustainability and to produce some economic and social benefits of sustainability (e.g., [35,115,117,124,175,202]). While the environmental goals of sustainability dominate in the discourse of the eco-city (e.g., [26,99,158,168,227]), the discourse of the compact city emphasizes the economic goals of sustainability (e.g., [95,109]), As regards the social goals of sustainability, they are of less focus in the eco-city compared to the compact city (e.g., [24,43,94,143,175,190]).

Furthermore, Jabareen [104] addresses the question of whether certain urban forms contribute more than others to sustainability, and subsequently proposes a matrix of sustainable urban forms that aims to help practitioners and policy makers in analyzing and assessing the contribution of these forms to sustainability according to their design strategies. The compact city is ranked higher than the eco-city in this regard. However, debating the most desirable sustainable urban form has been a long-standing scholastic question. In recent years, a major strand dominating this discussion emphasizes the benefits of the compact city for providing better conditions for its inhabitants (e.g., [9,13,67,80,105,142,159]). Overall, while the compact city has economic benefits, it is far from certain that the underlying principles are also beneficial in environmental and social terms. The eco-city is not immune to criticism when it comes to economic and social aspects. Designers, planners, and policymakers promote compact and ecological designs as the basis for sustainable development, but their effects are highly ambiguous.

In view of the above, it is of high relevance and importance to integrate the compact city and eco-city models so as to consolidate and harness their design strategies and environmental technologies to deliver the best outcomes of sustainability. Their integration is well justified by the fact that:

- the compact city needs to enhance its environmental performance;
- the eco-city needs to improve its social performance which is better in the compact city; and
- both contribute differently to economic sustainability, with the former focusing on mixed-land use strategy and the latter on green-tech innovation strategy.

Another argument supporting the integration of these two models is that they have already many overlaps among them in their ideas and concepts, as well as in their principles and policies. In short, the two models of sustainable urban form are compatible and not mutually exclusive, with some distinctive concepts and key differences. Some of the attempts undertaken to integrate these models tend to provide ideal approaches, combine some ideas from each one of these models to form new loosely integrated models, or to strengthen one model through adding principles from the other, all with the objective to add some missing aspects, or to attempt to balance the dimensions, of sustainability (e.g., [76,90,104,125,149,180,202]). For example, according to Roseland 180] and Harvey [90], a desirable eco–city has a well–designed urban layout that promotes walkability, biking, and the use of public transportation system; ensures decent and affordable housing for all socio–economic and ethic groups; and supports future expansion and progress over time. These dimensions are at the core of the compact city in terms of sustainable transportation and mixed land-use strategies. However, as this work is more often than not based on design with respect to the discipline of planning and architecture, it tends to emphasize more on creativity, common sense, ideal target pursuit, and future scenarios, rather than fact-based evidence explanation, empirically grounded research, or scientific finding-oriented exploration. This is in contrast to the eco-city and the smart city, which represent innovative models of urbanism based on a scientific approach to urban development [56].

Regardless, emphasizing one of the dimensions of sustainability remains a shortcoming (failure to meet certain standards in plans) and deficiency (lacking some necessary elements) in the urban context. Indeed, urban sustainability is a holistic approach to thinking, meaning that all the three dimensions of sustainability are equally important. Within the "sustainable urban form" debate, the idea of the "compact city" has been favoured, above other settlement patterns [e.g., the eco-city], in policy for a number of decades, although with less agreement by researchers in the field [222]. Yet the debates about them are rarely understood outside their expert communities. Holmstedt, Brandt and Robert [99] point out that implementing sustainable solutions in the context of the eco-city is more difficult because no unified practical definition is still accepted

Table 7
The contribution of the compact city to social sustainability.

- Creating a better quality of life through more social interaction, community spirit, and cultural vitality due to the access by proximity to facilities, workplaces, public spaces, public transportation, as well as the opportunity for walking and cycling
- Reducing crime and providing a feeling of safety through natural surveillance
- Improving social equity through better access to services and facilities and flexible design of housing in terms of mixed forms and affordability
- Maintaining public service level for social welfare by improved efficiency
- Greater accessibility due to lower cost enabled by shorter intra-urban distances
- Lowering transport costs, higher mobility for people without access to a car, and improved human health due to more cycling and walking
- Enhancing social cohesion through a sense of belonging and connectedness
- Supporting human, psychological, and physical health through ready access to open green space, walkability in neighborhoods, and social contact
- Enhancing livability in terms of social stability and cultural and recreational possibilities
- Healing spatial segregation by forging the physical links and bridging barriers between communities

Source: Bibri, Krogstie and Kärrholm [40].

even if the subject of sustainability has been hotly debated over the last four decades, and most projects act dishonesty in order to gain an advantage by not defining what is meant by sustainability and not meeting all its requirements. The concept of the eco–city has, in policymaking and planning, tended to focus mainly on the underlying structure of urban metabolism—sewage, water, energy, and waste [96], falling short in considering economic and social issues as well as smart solutions.

Many city governments within the ecologically advanced nations (e.g., Sweden, Denmark, Germany, the Netherland, and the UK) are increasing supporting new development projects as central demonstration sites for ecologically and economically sustainable urban development. The recent smart eco-city projects (e.g., [37,197]) marketing themselves as models for future sustainable development represent only sites of experimentation, behaving in ways that focus on integrating environmental and economic goals while adopting data-driven technologies and enhancing environmental technologies. The idea of experimentation is associated particularly with the tendency for new smart technologies and ways of working to be trialled at a limited scale, often through cross-sectoral partnership approaches for learning purposes (see, e.g., [45,74,122,133]). Emerging smart eco-cities function “as a potential niche where both environmental and economic reforms can be tested and introduced in areas which are both spatially proximate (the surrounding region) and in an international context (through networks of knowledge, technology and policy transfer and learning)” Späth [[197], p. 1].

4.1.2. Smart solutions for social sustainability

Conventional paradigms of urbanism require new responses under the current circumstances, whether in relation to sustainability or technology. The scales and complexities of contemporary urbanization fundamentally disrupt the challenges that urbanism research and practice have to deal with. The compact city and the eco-city are the quintessential examples of paradigms that are adopted just as much as they are advocated and criticized in the context of sustainability and technology. In this regard, it is worth elaborating on the social dimension of sustainability in the context of compact cities and eco-cities from a technological perspective. The compact city offers several benefits of social sustainability (e.g., [44,46,64,95,109,114,190,223]). This is demonstrated by a comprehensive case study conducted by Bibri, Krogstie and Kärrholm [40], of which the results concerning the social benefits of the compact city are presented in Table 7.

As regards the eco-city, social proposals are conversely usually couched in speculative language in terms of investments, ventures, and employments, or the social aspects of sustainability are simply overlooked, such as social equality, social integration, and access to public services. These issues reflect the challenge of incorporating social sustainability into a design-oriented and technology-led approach. In the existing literature on urban sustainability, the societal factors are shadowed by the ecological aspects [140], as well as ignored in assessment methods [14]. Nevertheless, according to a recent case study conducted by Bibri and Krogstie [35] on two of the leading examples of eco-districts in Europe, a set of new measures have been developed and implemented that are expected to strengthen the influence of the social goals of sustainability over urban development practices. One of the key strategies of sustainable development underlying the program for one of these two eco-districts is “participation and consultation.” This is deemed of crucial importance for improving social cohesion based on the argument that the sustainable urban district can only be created by the cooperation between residents and businesses, the city’s administrations and companies, property owners, academics, and other stakeholders through dialogue in order to shape and manage the eco-district in question. However, the case study revealed that there is a lack of structures for collaboration between the different stakeholders of the eco-district.

Nonetheless, new and emerging technologies have much to offer in the context of social sustainability. A prevalence of the socially oriented aspects of sustainability is observed in smart cities [206]. This may be explained by the symbiotic relationship between advanced ICT and urbanization. In this respect, the human nature of urbanization and the social issues engendered by urban growth, such as social deprivation, community disruption, crime and insecurity, socio-economic disparity, social inequality, and public health decrease have underlined the importance of the social aspects of sustainability in emerging smart sustainable cities due to their potential to move beyond narrow environmental and economic objectives and to tackle social issues. Especially, in smart cities, technologies more often than not come first and resolutions to social problems come second [98,153]. Among the scientific challenges of smart cities of the future are to develop technologies that ensure equity, fairness, and enhance the quality of city life, and to ensure informed participation and create shared knowledge for democratic city governance [12]. The second generation of the smart city is framed as a decentralised, people-centric approach where smart technologies are employed as tools to tackle social problems, foster collaborative participation, and address the needs of citizens [208].

The socially oriented aspects of sustainability in smart cities focus on the quality of life and the efficient use of the human capital. However, while ICT companies are developing technologies and “solutions that cater to…governmental agencies…and civic society, it is currently unclear whether these technologies facilitate the scope of improvement of the “general” quality of life of all citizens, or whether they benefit a specific “elitist” part of society that is digitally skilled and can financially afford these solutions, while excluding another one” ([206], p. 7). Another aspect of social sustainability pertaining to smart cities is citizen participation, particularly in relation to innovation, governance, and democratization (e.g., [12,36,163,164]). These promises and ideas are usually advocated by ICT companies. Seçkiner Bingöl [191] analyzes the relationship between the concepts of smart sustainable cities and citizen participation, and discusses how the latter is shaped, focusing on seven types of mechanisms of citizen participation. The author found that citizen participation is only considered as a set of mechanisms aimed at supporting good governance, and accordingly recommends using these mechanisms to highlight other aspects of sustainability, such as securing comprehensiveness, promoting gender equality, and to focus on other aspects of citizen participation, such as real participation and democratic effectiveness. Based on case study analysis, Hatuka and Zur [100] argue that the initiatives that focus on social needs and address inequality in smart cities are still at the margins, and by means of conclusion, they call for shifting the focus from the city to society in developing digital initiatives and cultivating smart social urbanism.

Based on interdisciplinary case studies, Bibri and Krogstie [39] provide a detailed set of recommendations in the form of strategic pathways on how to implement, in addition to smart citizen participation and consultation, smart public safety and smart healthcare in the context of data-driven smart sustainable cities of the future. The authors frame these recommendations from the perspective of the social infrastructure, and particularly argue that the involvement of citizens in the city management using advanced information systems is crucial to the progress of urban sustainability Such involvement is associated with the adoption of the most important resolutions related to living, which intend to improve the level of satisfaction and increase the level of confidence and trust among citizens in the city administration. In addition, [83] investigate, in their study on smart tools for socially sustainable transport, how smartphone applications can address social sustainability challenges in urban transport, if at all, with a particular focus on the transport disadvantages experienced by citizens due to low income, physical disability, and language barriers. This study reveals, based on a review of 60 apps, that transport apps have the potential to address or respond to the equity and inclusion challenges of social sustainability by employing universal design in general–use apps, including cost–conscious features, providing language options, and specifically developing smartphone apps for persons with disabilities. All in all, it can be argued that the smart city provides great potential to enhance the performance of compact cities and eco-cities in regard to the different aspects of social sustainability.

4.2. Sustainable urban forms: problems, issues, and challenges

The form of the contemporary city has been a salient factor for enacting cities that are more sustainable, efficient, equitable, and livable. It was the widespread diffusion of sustainable development in the early 1990s that gave a major stimulus to the question regarding the contribution that certain urban forms as human settlements might make to sustainability. Sustainable development continues to stimulate the discussion and provoke thoughts about the form of the city in light of the mounting challenges facing the world and the societal transformations triggered by the advances in science and technology. Besides, the rate and scale of urbanization will escalate over the coming years, and consequently, sustainable cities will face new challenges, including creating cost-efficient environments, improving life quality for citizens, maintaining economic growth, and being able to handle non-static and complex concepts that evolve over time. In the current climate of the unprecedented urbanization of the world, it has become even more challenging for sustainable cities to reconfigure themselves more sustainably without the use of advanced ICT [39]. Therefore, policymakers, planners, and mangers within the ecologically advanced nations, or those countries that are known for their high level of sustainable development practices, need to promote, develop, and implement innovative solutions for operational management and sophisticated approaches to development planning to contain the negative effects of urbanization.

The intractable issues engendered and special conundrums posed by urban growth exacerbate the wicked problems already characterizing sustainable cities as complex systems. The consequences of urbanization are associated with intensive energy consumption, poor water quality, air and noise pollution, public health decrease, toxic waste disposal, resource depletion, poor housing and working conditions, saturated transport networks, traffic congestion, social inequalities, socio-economic disparities, and inefficient management of outdated infrastructures. Urban growth may jeapordize the sustainability of sustainable cities as it puts an enormous strain on urban systems and great demand on natural resources and ecosystem services. Especially, the experience of the past decades has shown that the conventional approaches to urban planning and development based on interventions promoting renewed access to urban life have been inadequate to cope with the adverse impacts of urbanization, high population growth, and rapid changes facing sustainable cities. All in all, new circumstances require new responses concerning the development planning and operational management of sustainable cities in order to be able to respond to the changes in socio-economic needs of citizens and to tackle the environmental pressures on urban environments, as well as to keep up with societal transitions and global trends.

Moreover, yet knowing if we are actually making any progress towards sustainable cities is problematic. There is a very contradictory, conflicting, and fragmented picture that arises of change on the ground. Given these complex conditions, it is sometimes hard to see where the common challenges of sustainable cities may be identified. What lies at the heart of these challenges is the conceptualization of sustainable cities with regard to their progress. This pertains to the kind of changes that need to be made and to how progress can be assessed when it comes to developing or enhancing models of sustainable urbanism. Indeed, producing theoretically and practically robust models of sustainable urban form has been one of the most significant intellectual and practical challenges since the early 1990s (e.g., [32,34,104,121,160,222]). As concluded by Jabareen [[104], p. 48], "neither academics nor real-world cities have yet developed convincing models of sustainable urban form and have not yet gotten specific enough in terms of the components of such form." This implies that it has been very difficult to translate sustainability into the built form of cities. Indeed, sustainable urban forms epitomize complex systems par excellence, more than the sum of their parts and developed through a multitude of individual and collective decisions from the bottom up to the top down. As such, they are full of contestations, conflicts, and contingencies that are not easily captured, steered, and predicted respectively. In a nutshell, they are characterized by "wicked problems" [179]. This means that the physical, environmental, economic, and social problems of sustainable cities are difficult to define, unpredictable, and defying standard principles of science and rational decision–making. As a consequence, when tackling wicked problems, they become worse due to the unforeseen consequences which were overlooked because of treating the system under study in too immediate and simplistic terms, or failing to approach that system from a holistic perspective. Rittel and Webber [179] argue that the essential character of wicked problems is that they cannot be solved in practice by a central planner. Wicked problems are so complex and dependent on so many intertwined factors that it is hard to grasp what they exactly are and thus how to tackle them. Therefore, it is impossible to plan sustainable cities as urban complexities due to the lack of a complete form of knowledge of the consequences of interventions, which is evidently impossible [150].

Furthermore, it is difficult to evaluate the extent to which the existing models of sustainable urban form contribute to sustainability. Indeed, it is not evident which of these models is more sustainable, although there seems to be a consensus on topics of relevance to sustainability within research on sustainable urban forms. There is a lack of agreement about the most desirable urban form in the context of sustainability (e.g., [104,223]). As a result, city governments, planning experts, and landscape architects are grappling with the dimensions of the existing models of sustainable urban form by means of a variety of planning, design, and policy approaches. What is known about the relationship between planning and design interventions and sustainability goals is a subject of much debate. This means that realizing sustainable urban forms require making countless decisions and complex negotiations about urban form, ecological design, urban design, sustainable technologies, policy measures, and governance arrangements. Moreover, the conflicts and contradictions associated with sustainable urban development thinking and practice will continue without conceptual anchor [222].

In addition, it is not an easy task to judge whether or not a certain sustainable urban form is actually sustainable, irrespective of the spatial scale at which such form may be considered. To some extent, the problem relates to the dilemma of form and function or structure and process, and the way this dichotomy has been conceived and approached, i.e., set up a relationship between cause and effect. New urbanism “is by necessity a fully planned and regulated environment, fiercely resistant to change and a fully a fully planned and regulated environment, fiercely resistant to change and any deviation from the rigid rules that govern its form and function. But it is precisely this inflexibility, which is so important in its struggle for completion as a development enterprise” ([61], p. 64). However, Neuman [[160], p. 23] argues that the form of the city is “both the structure that shapes process and the structure that emerges from a process.” It follows that if form “is an outcome of evolution” ([160], p. 23), then the arrangement of how to undertake planning in ways that support and guide such an evolutionary process becomes a key issue. This implies reversing the focus on urban forms governed by static planning due to its inherent limitations in achieving the goals of sustainability. Durack [61] argues for open, indeterminate planning due to its advantages, namely, cultural diversity; tolerance and value of topographic, social, and economic discontinuities; citizen participation; and continuous adaptation, which is common to human settlements like all other living organisms and systems.

The stable relationships between a set of sustainable activities and a certain urban form are not easily generalizable on the basis of form–function [121]. It is widely acknowledged that the integration and balancing of the dimensions of sustainability is conflicting and contradictory, as the different aspects of sustainability rely on the different criteria for desirable outcomes. Consequently, planners will in the upcoming years “confront deep-seated conflicts among economic, social, and environmental interests that cannot be wished away through admittedly appealing images of a community in harmony with nature.” ([48], p. 9) Such conflicts also involve spatial interests. Focusing on the urban scale, Kärrholm [121] sheds more light on tendencies toward scale stabilization, i.e., the tendencies of planning from the perspective of only one or a few pre-fixed scales. The same endeavor to apply sustainable development to urban form might increase one aspect of sustainability (e.g., environmental) on one scale (e.g., the urban) while decreasing it on another (e.g., neighborhood).

Indeed, research in the field of sustainable urban form, especially compact cities and eco-cities, has, over the last two decades, produced contradictory, uncertain, weak, non-conclusive, and questionable results (e.g., [24,55,101,119,121,143,160,222]). The overall outcome of this research relates mostly to the actual benefits and effects claimed to be delivered by the design strategies adopted as part of the planning of sustainable cities. In a nutshell, the issue of sustainable urban form has, both in discourse and practice, been problematic. Much of what we know about sustainable cities to date has been gleaned from studies that are characterized by data scarcity and employ traditional data collection and analysis methods with inherent limitations, biases, and constraints, often as a result of relying on selective samples. This adds to the focus on long-term approaches to city planning, the inability of simulation models to address the current conceptions of the city as a complex system in terms of its future design, and the inefficient mechanisms used in city operational management. It follows that most of the inadequacies, shortcomings, struggles, and bottlenecks related to sustainable urban forms are due to how these human settlements have been studied, understood, planned, designed, and managed for several decades. We still know very little about the majority of human settlements.

The model of the city is no longer predicated on the basis that the city is a stable unchanging structure, but rather one that is more and more dominated by information flows, with no physical traces, reflecting the complexity of socio-economic and technical processes occurring in urban spaces and the unpredictability of various internal and external factors. This brings us to the issue of conceiving cities in terms of forms and pre-fixed scales as being inadequate to achieve the goals of sustainable development. Rather, urban forms and their spatial scaling should be conceived in terms of the outcomes of the processes of urbanization. This conception holds significant potential for attaining the elusive goals of sustainable development, as it enables sustainable urban forms together with their spatial scaling to be dynamic in planning, scalable in design, and efficient in operational functioning. This indeed raises the right questions of whether and to what extent the processes of building, scaling, and expanding the city and the processes of living, consuming, producing, and moving in the city are sustainable. Besides, a well–established fact is that cities as complex systems evolve and change dynamically, and the underlying theoretical and practical knowledge of planning and design should respond accordingly. This calls for advanced technologies and their novel applications in order to respond to urban growth, environmental pressures, changes in socio–economic needs caused by urbanization, among others. Especially, there is a symbiotic relationship between urbanization and ICT.

The problems, issues, and challenges facing sustainable cities are more complex due to the increasing flows and channels of information, the divergence of agents, the heterogeneity of actors, the prevailing processes of globalization, the dispersion of power, and the difficulty of decision making. This is drastically changing thanks to the clear potential and substantive effects of big data technologies on urban studies, urban analytics, urban processes, and urban practices. The abundance of urban data, coupled with their analytical power, opens up for new opportunities for innovation in sustainable cities, particularly in relation to linking their infrastructures to their operational functioning and planning through control, optimization, management, and improvements, and thus tightly interlinking and integrating their systems and domains. Unlocking the potential of urban data and leveraging it in the transition towards sustainability implies addressing and overcoming the problems, issues, and challenges facing sustainable cities in their endeavor to achieve the long-term goals of sustainability.

Indeed, it has been argued that sustainable cities need to embrace and leverage what smart cities have to offer in terms of advanced technology solutions so as to achieve the desired outcomes of sustainability under what is labelled “data-driven smart sustainable cities.” This brings us to the question related to the weak connection between sustainable cities and smart cities as approaches and their extreme fragmentation as landscapes at the technical and policy levels, adding to their opposite conceptual characteristics and existing tensions (e.g., [7,20,31,63,151,200,206,228]).

4.3. Data-driven smart sustainable cities

4.3.1. Societal trends: global, scientific, and technological shifts

The fundamental role of cities in driving sustainable development interplays with major societal trends to which all cities, including sustainable cities, must adapt, but which also produce new opportunities. As with all paradigms of urbanism, data–driven smart sustainable cities have emerged and materialized as a result of responding to an amalgam of several forms of prevailing and emerging societal trends (Table 8), as well as to the problems, issues, and challenges to sustainable cities. These trends as a congeries of forces will also shape the expansion, success, and evolution of this new paradigm of urbanism.

Smart sustainable cities are about recognizing the link between the major societal trends shaping modern society at a growing pace, namely the rise of digitization, the spread of urbanization, and the diffusion of sustainability, and then finding ways to unlock and explore the potentials and opportunities of interlinking these developments for reaching a desirable future.

Transforming and advancing sustainable cities is increasingly justified by the need to monitor, understand, analyze, plan, and manage their infrastructures and systems in new and innovative ways to achieve the desired outcomes of sustainability. This is increased by the ongoing quest and growing motivation for achieving the SDG 11 [212] and responding to the unintended effects of urbanization. Nonetheless,

Table 8
The key societal trends behind data-driven smart sustainable cities.

Forms of Trends	Prevailing and Emerging Trends
Global trends	Sustainability, ICT, urbanization, and globalization
Academic discourses	Sustainable urbanism, compact urbanism, ecological urbanism, smart urbanism, data-driven urbanism, scientific urbanism, and sustainable urban development
Urbanism paradigms:	Sustainable cities, smart cities, smart sustainable cities, and data-driven smart sustainable cities
Computing paradigms	Ubiquitous computing, sentient computing, the IoT, big data computing, quantum computing, cloud computing, fog computing, edge computing, and distributed computing
Scientific paradigms	Data–intensive science (data-driven science and empiricism), big data science, empirical evidence, scientific theory, and computational science
Technological trends	Bg data analytics, the IoT sensing, Artificial Intelligence, datafication, Blockchain technology, virtual reality, 5G, and drone technology

urbanization can have many positive outcomes and can foster human development. In more detail, it creates enormous environmental, social, economic, and spatial changes, which provide an opportunity for sustainability with the potential to apply advanced technologies in order to use resources more efficiently and control them more safely, to promote more sustainable land use, and to preserve the biodiversity of natural ecosystems and to reduce pressure on their services, with the ultimate aim to improve economic and societal outcomes.

4.3.2. City operational management and development planning: urban computing and intelligence

We currently experience accelerated digitalization and intensive datafication of society, and we see the dawn of the digitalized and datafied society in everyday life, manifested in the various forms of urban computing and intelligence pervading the very fabric of the contemporary city. Urban computing and intelligence can generate deep insights that can be used to make more informed and fact-based decisions, and can also create feedback loops between humans and their activities and the urban environment. At the core of urban computing and intelligence is datafication (e.g., [50,54,129,199]) represents an urban trend which defines the key to core city operations and functions through a reliance on big data computing and its core enabling and driving technologies. It is also a contemporary phenomenon which denotes the quantification of urban life through digital information for environmental, economic, and social values. Cities require data to extract knowledge to perform critical urban processes and practices and to develop and implement plans and strategies to achieve key objectives. Therefore, they are increasingly dependent upon their data to operate properly—and even to function at all. They are currently taking any possible quantifiable metric and squeezing value out of it to enhance decision–making pertaining to a wide variety of practical applications and uses in relation to many urban systems and domains. In a modern urban landscape, a city's performance is measured, monitored, evaluated, and enhanced based on the ability of having control over the storage, management, processing, and analysis of the urban data, as well as on the knowledge derived from these data in the form of applied intelligence. Tackling the challenges of sustainability and mitigating the negative effects of urbanization are among the key concerns of the datafication of the contemporary city.

In view of the above, all traditional mechanisms of the city management (administration, organization, and planning) are gradually replaced with digital mechanisms enabling and supporting data-driven decision making. Data-based city management relies on urban computing and intelligence for implementing the data-driven technology solutions developed for the various spheres of the city administration, including, but are not limited, to:

- Transport management
- Traffic management
- Street lighting management
- Mobility management
- Waste management
- Energy management
- Environmental monitoring
- Building management
- Public safety
- Healthcare and education
- Planning and design
- Governance

Data-based city management involves a number of agencies that use technologies for generating, processing, and analyzing data to adopt solutions for improving and advancing sustainability. It is a basic driver for the transformation of urban operations, functions, and services, and therefore, it is expected to dramatically change the principles of managing urban environments. As a set of mechanisms, data-based management entails the utilization of advanced knowledge services and concrete projects through new and emerging technologies to benefit people immensely in a variety of ways and to make urban environmental more liveable and attractive. In doing so, it leads to further developments and innovations in environmental, economic, and social sustainability. In addition, it brings cohesion and congruence to urban strategies and unifies the expectations of different urban actors in ways that render plans feasible and adequate to the daily reality of urban places, and that facilitate a shared vision of sustainable development.

According to Bibri [27], managing sustainable cities is a very complex function that encompasses approaches, strategies, and instruments that make them work. This means that:

- Their infrastructures are accessible, functional, and constantly improved.
- Their energy systems are sustainable and efficient.
- Their urban metabolism and natural resources are optimized.
- The needed public services and natural resources are available and equitably distributed among people.
- Their designs are scalable and integrative.
- Their plans are comprehensive, dynamic, and innovative.
- The interests of the different stakeholders, especially citizens, are well represented and counted in decision making processes and in future developments.
- Their economy is sustainable, green, and prosperous.

Sustainable urbanism is increasingly emphasizing the importance of big data technologies and their novel applications in improving and advancing sustainability. Indeed, there has been a conscious push for sustainable cities across the globe to be smarter and thus more sustainable by developing and implementing data-driven technology solutions in their different spheres so as to enhance their designs, strategies, and policies and thus optimize operational efficiency, strengthen infrastructural resilience, and improve social equity and life quality. This trend is evinced by many topical studies conducted recently on sustainable cities, especially eco-cities (e.g., [18,27,37,39]; [93;167a, b; 186,187,197,201,204,207,226]). This implies that the recent advances in urban computing and intelligence associated with monitoring, understanding, analyzing, planning, and managing smart cities are increasingly being adopted by sustainable cities to boost and maintain their performance with respect to sustainability—under what has been termed "data-driven smart sustainable cities."

Urban computing and intelligence (e.g., [29,33,111,144,229,230,231,232]) has recently gained attraction for its vast potential for building data-driven smart sustainable cities [29]. It represents a holistic approach to harnessing and exploiting the vast troves of big data in cities to improve urban forms, urban infrastructures, urban environments, and urban services, as well as urban operational management and development planning systems. The big data deluge produced by sensing technologies and large-scale computing infrastructures provide rich knowledge about how cities function and can tackle complex challenges. The efforts "dedicated to connecting unobtrusive and ubiquitous sensing technologies, advanced data management and analytics models, and novel visualization methods to structure intelligent urban computing systems for smart cities" ([144], p. 675) are being directed towards developing new applied solutions for the planning and operational functioning of sustainable cities, especially eco-cities (e.g., [37,187; 197; 226]).

As part of the ICT infrastructure of smart cities, which is empowered by the IoT technologies and advanced algorithms and techniques that can collect and handle massive datasets, urban computing and intelligence will bring new advances in many technological areas in order to cope with the challenges of implementing applied data-driven solutions in real-world settings. These area include but are not limited to:

- Horizontal information platforms
- Operations systems and dashboards
- Innovation labs for urban intelligence and planning functions
- Hybrid systems bridging the physical and digital world
- Urban ubiquitous and intelligent sensing infrastructure
- Smart network infrastructure
- Big data infrastructure for urban analytics
- Artificial intelligence models
- Real-time urban data processing and analysis
- Novel learning methods for urban data clustering and classification and data analytics
- Data mining and machine learning for data-driven smart sustainable cities
- Intelligent energy management for urban sensing and urban computing
- Urban environment monitoring, analytics, and prediction
- Cloud of Things for smart environments
- Visual analytics and visualization methods
- Incremental and distributed mining strategies for big data scalability
- Security and privacy mechanisms

Urban computing and intelligence has recently attracted much attention from both academia and industry for tackling many problems and issues related to urbanization and sustainability. It can bridge the gap between unobtrusive and ubiquitous sensing, intelligent computing, cooperative communication, and massive data management and analytics. This is to create novel solutions for sustainability by means of cloud and fog computing, the IoT, device to device (D2D) communication, data analytics techniques, Artificial Intelligence, simulation models, visual analytics methods, and intelligent decision support systems. In view of that, urban computing and intelligence may overcome one of the scientific challenges pertaining to sustainable cities—relating their built infrastructure, urban infrastructure, economic infrastructure, and social infrastructure to their operational functioning and development planning. This will enable sustainable cities to leverage their collective intelligence in making actual progress towards integrating and balancing the dimensions of sustainability. This is owing to the core enabling and driving technologies of big data computing offered by smart cities in relation to or for sustainability (e.g., [7,16,20,36,91,134,163,170,172,176,188,192,200,203,208]). Smart cities offer the enticing potential of environmental improvement and socio–economic development, as well as the renewal of urban centers as hubs of innovation and research (e.g., [97,127,129,131,135,164]).

The processes and practices of sustainable urbanism are becoming highly responsive to a form of data-driven urbanism. One of the consequences of data-driven urbanism is that the systems and domains of sustainable cities are becoming much more tightly interlinked and coordinated respectively. And also, vast troves of data are being generated, analyzed, harnessed, and exploited to understand the multiple complexities of sustainable cities so as to make them safer, cleaner, more liveable, more equitable, more resilient, and, above all, more organized. Indeed, the intersection of complexity science and big data analytics is making it possible to reveal hidden regularities in the organization of cities. This allows to better anticipate or predict the systemic behavior that result from the many interactions of all the components that make up sustainable cities, which is necessary for developing advanced simulation models and optimization methods that address new conceptions of how sustainable cities function as complex systems.

The application of big data technologies to urban systems is founded on the integration of data science, computer science, information science, urban science, complexity science [12,16,129], sustainability science, urban sustainability science, and data-intensive science [21]. Bibri [29] provides a detailed account of the scientific and academic disciplines underlying data-driven smart sustainable urbanism, as well as a framework illustrating their integration and fusion from an interdisciplinary and transdisciplinary perspective. These disciplines are at the core of the emerging approaches to building simulation models that are able to respond to various properties of complex systems. However, while complexity gives no way whatsoever to precisely predict the future [173], it is still theoretically possible to make accurate predictions about urban dynamics and changes on the basis of the knowledge that is as good as possible as to the equations describing the systemic behavior of sustainable cities. Hayek [92] explains that complex phenomena can only allow pattern predictions using modeling approaches, compared to the precise predictions pertaining to non–complex phenomena.

A deeper understanding of the dynamical properties of complex systems is crucial to bringing about drastic changes to both the simulation models that we are able to build based on big data analytics and at different spatial scales and over different time spans, as well as to the way in which the underlying technologies can inform planning and decision processes. Such properties are at the core of the new conceptions of how smart cities and sustainable cities can be planned and designed (e.g., [12,19,29,150]). Specifically, as a set of interacting subsystems, the city should be built in a way that is scalable, resilient, stable, and balanced by incorporating such dynamical properties as self–organization, emergence, adaptation, feedback loops, nonlinearity, and evolution. What is crucially important in the quest for making the city function as a social organism is deeper knowledge on how complex systems function and its effective incorporation in the very design, engineering, and modeling of the technological systems used to monitor, understand, analyze, and plan the city for improving sustainability, efficiency, and resilience.

To plan sustainable cities as complex systems requires having a complete form of knowledge of the consequences of interventions and organizations. Otherwise, there is a difficulty in planning the kind of urban complexities that are seen in sustainable cities such as compact cities [150]. In addition, comprehensive planning remains practically impossible, especially in large sustainable cities, due to the kind of wicked problems they embody. Wicked problems are difficult to explain and impossible to solve because of incomplete, contradictory, and changing requirements that are not easy to recognize. Bettencourt [16] attempts to reformulate some of Rittel and Webber's [179] arguments in a modern form in what is called the "planner's problem," which has two distinct facets: (1) the knowledge problem and (2) the calculation problem. The first problem refers to the planning data needed to map and understand the current state of the city. It is conceivable that urban life and physical infrastructure could be adequately sensed in several million places at fine temporal rates, generating huge but manageable rates of information flow using the various forms of advanced ICT. It is not impossible, albeit still implausible, to conceive and develop technologies that would enable a planner to have access to detailed information about every aspect of the infrastructure, services, social lives, and environmental states in the city. The second problem refers to the computational complexity to carry out the actual task of planning in terms of the number of steps necessary to identify and assess all possible scenarios and to choose the best possible course of action. Unsurprisingly, the exhaustive approach of assessing all possible scenarios is impractical due to the fact that it entails the consideration of impossibly large spaces of possibilities. But what this reformulation does promise is an ability to provide a powerful means for envisioning and predicting future scenarios in ways that were inconceivable a decade ago.

The emerging simulation models and optimization methods (e.g., [12,62,72,85,88,120,138,145,166,183,218,225]) are increasingly being embraced by sustainable cities to deal with the complexities they inherently embody. This relates to urban intelligence functions, which represent new conceptions of how data-driven smart sustainable cities function and utilize, integrate, and harness complexity science, urban complexity theories, sustainability science, urban sustainability theories, urban science, data science, and data-intensive science in constructing powerful new forms of simulation models and optimization methods that can generate urban forms, urban structures, spatial organizations, and spatial scales. These designs are intended to advance sustainability, optimize efficiency, improve equity, strengthen resilience, and enhance the quality of life. Bibri [29] analyzes the enabling role and innovative potential of urban computing and intelligence in the strategic, short-term, and joined-up planning of data-driven smart sustainable cities of the future. The author argues that the fast-flowing torrent of urban data, coupled with its analytical power, is of crucial importance to the effective planning of data-driven smart sustainable cities of the future thanks to the advanced form of intelligent decision support enabled by urban computing and intelligence. The sort of urban intelligence and planning functions envisaged for data-driven smart sustainable cities are associated with their designs, strategies, and policies in terms of development planning, which in turn shape and drive their operations, functions, and services in terms of operative management. However, urban computing and intelligence involves significant challenges. As the size of the city increases, the total operational and maintenance costs and the consumption of resources will rise, the performance will decrease, the networks proliferate, and the security of the systems become subject to serious threats and vulnerabilities. In addition, urban intelligence has been subject to critique in terms of its operation and nature. Opening the notion of intelligence to contestation, Lynch and Del Casino [148] examine differing conceptions of intelligence and what they might entail with regard to how to approach the theorization of “smart” spaces. The authors argue for a view of intelligence as multiple, partial, and situated in and in-between spaces, bodies, objects, and technologies, as well as call for attentiveness to the ways in which particular intelligences are prioritized over others—which may be suppressed or neglected—through the production of smart spaces in the context of our rapidly changing understandings of the “humanness” of intelligence.

However, data-driven smart sustainable cities need to evolve urban intelligence and planning functions in response to the emerging trend of building models of smart cities and sustainable cities functioning in real time from routinely sensed data. This is coupled with ubiquitous sensing getting closer to providing quite useful information about longer term changes (see, e.g., [6,12,37,127,163,185]). Urban intelligence functions are associated with the control, management, optimization, and enhancement of the operating and organizing processes of urban life. As such, they involve different data analytics components, including data sources, system components, enabling technologies, functional elements, and analytics types (i.e., descriptive analysis, diagnostic analysis, predictive analysis, prescriptive analysis, and inferential analysis). These components are used to gather and manage data on a variety of urban systems (mobility, traffic, transport, energy, environment, water, waste, etc.), to model urban phenomena, and to provide the necessary simulation and visualisation tools to be integrated into decision support systems. A number of recent studies have addressed the emerging data-driven smart approaches to urban planning for the different areas of sustainability in the context of both smart cities and sustainable cities (e.g., [6,11,16,17,23,29,167,176,187,192]).

Overall, the ever-increasing deluge of urban data epitomizes a drastic change in the kind of data that can be generated about urban systems and environments as regards what happens and might happen where, when, why, and how so as to devise more effective actions and measures for enhancing the planning and design of data-driven smart sustainable cities. Big data analytics is bringing about major transformations in understanding and redefining the problems and issues of sustainability in new and innovative ways for more effective planning and efficient design. In particular, it is pushing planning into short termism as regards how emerging data-driven smart sustainable cities function and can be managed, which adds a whole new dimension to urban sustainability by shifting away from long–term strategic planning. Short–termism in planning is about measuring, evaluating, modelling, and simulating what takes place in the city over hours, days, weeks, or months instead of years, decades, or generations, and creating a set of actions and measures to improve performance with respect to the various areas of sustainability. Moreover, big data analytics is enabling what is called joined-up planning, a form of integration that enables the system–wide effects of environmental, economic, and social sustainability to be tracked, understood, analyzed, and built into the designs, technologies, and responses that are features of the operations and functions of sustainable cities.

Concerning the pursuit of data for decision making, the ideal "pure-type" data collection system is in fact unobtainable and the actual management is done by imperfect and incomplete information as decisions cannot wait for the data to be caught, refined, and analyzed in dynamic systems such as those found in the city. This has to be addressed as an ongoing issue, or with a credible claim that information systems have caught up with real-time processes. This is predicated on the assumption that there will always be more new and different sources of data that need to be collected and conjoined, an issue which curtains the opportunity to explore the real potential of the aggregation of real-time data to deal with changes in the context of data-driven smart sustainable cities. Nonetheless, what new developments promise is an ability to have a real time view of changes at different spatial scales and over different time scales and to deal with these changes early on to mitigate the risks and unintended consequences of the actions and choices of urban stakeholders with respect to sustainability.

4.3.3. A critical understanding of smart urbanism: risks and implications

4.3.3.1. Science, Technology, and Society (STS) linkages and concerns. Science-based technology is well aligned with the endeavor to create and enact visions for sustainable futures. Advances in science and technology (S&T) inevitably bring with them wide–ranging common visions on how cities will evolve in the future, as well as the opportunities and risks that future will bring [30]. The opportunities relate to the role of science–based technology in society in terms of its progress, and the risks are associated with the drawbacks, deficiencies, and challenges of science-based technology in relation to the people living in society. The focus in this context is on the advantages and disadvantages of big data science and analytics and the associated technological applications in advancing urban sustainability. Big data science and analytics as an area of S&T embodies an unprecedentedly transformative power—manifested not only in the form of transforming the knowledge of sustainable urbanism, but also in enhancing its practices and fostering its progress—with some downsides.

Smart urbanism represents multiple visions for the future of new technologies, infrastructures, services, as well as urban places and their characteristics, such as function, land use, form and hierarchy of settlement, and how it grows and evolves. It is important to understand and value the multiplicity of socially constructed potential futures—yet with some coherence of purpose and conceptual anchor. The discourse of smart urbanism is deeply originated in normative visions of the future where the salient driving factor for transformation is technology and its constant advancement. However, not only is our current understanding of the opportunities and risks of smart urbanism limited [146], but we should also expect some pitfalls that are yet to be seen, as new advancements in big data analytics and Artificial Intelligence will emerge together with unanticipated changing directions of their use for other purposes than what people wish. This is predicated on the assumption that all technological developments come with their dark side. Indeed, future models for smart cities have been extensively critiqued in the literature for reflecting techno-utopian, neoliberal approaches to urban development. While advanced technologies can bring numerous advantages to urban sustainability, it is important to acknowledge the fact that they can be problematic, and therefore, policy-makers and planners should be careful when employing them.

The significant risks of smart urbanism calls for critically engaging with its far-reaching societal implications. The literature on smart urbanism appears most frequently focused on the realization of technological solutions [141], such as big data computing, cloud computing, the IoT, Artificial Intelligence, 5G, and industry 4.0, rather than providing a critical understanding of its conceptual undermining and negative implications. There is a lack of the theoretical basis and empirical evidence required to holistically evaluate the potential effects and hidden agenda of the transformative processes within smart urbanism in connection with the practices, operations, and institutions of modern society [28]. A number of studies have been carried out in more recent years that address the ramifications of smart urbanism and the related driving socially disruptive technologies, drawing on several theories and theoretical positions.

4.3.3.2. Social construction of big data technology . The ways the technical systems are designed, operated, and steered is influenced by what Foucault [[79], p.194] calls a “dispositif” and defines it as “a thoroughly heterogeneous ensemble consisting of discourses, institutions, architectural forms, regulatory decisions, laws, administrative measures, scientific statements, philosophical, and moral propositions.” In this context, a data assemblage possesses, in Kitchin’s [128] terminology, systems of thought, regulatory environments, organisational priorities and internal politics, institutional collaborations, funding and resourcing, technical know–how, and marketplace demand. The institutional apparatuses and their techniques are at the core of what Foucault [78] terms “power/knowledge,” that is, knowledge produced by a system of procedures to fulfil a strategic function. With that in mind, seeing cities through big data is contingent, biased, framed, and selective for the purpose of achieving certain end goals, i.e., to monitor, empower, dictate, discipline, regulate, control, steer, centralize, make profit, and so forth. So, the new possibilities of big data analytics, distributed sensor systems, and ubiquitous computing are promoting a false idea of value-free and objective knowledge. Indeed, the data used in cities do not exist independently of the instruments, systems, platforms, practices, processes, and knowledge employed—and embedded within a multidimensional context (e.g., local, national, social, political, cultural, organizational, regulatory, etc.)—to generate, process, and analyze these data for decision-making purposes. To put it differently, data are never raw, but always already cooked to a particular recipe for a particular purpose [87]. Big data technologies are socio-technical in nature and thus shaped by philosophical ideas, socio-political frameworks, and ideological positions. In other words, they are inherently cultural, which is manifested in creating the kind of discourses that prioritize specific ideas, claims, assumptions, and visions about the nature and practice of science and technology in society. Therefore, there is a need to critically unpack how data are handled and put at work. In addition, data-driven smart urbanism remains selective, flawed, biased, normative, and politically inflected, although it purports to produce a commonsensical, neutral, apolitical, evidence–based form of urban planning and governance (e.g., [22,127–129,146,194]). Consequently, impartiality, which holds that decisions should be based on objective criteria rather than on the basis of bias and prejudice, is unlikely to prevail over partiality in the era of big data.

4.3.3.3. Technocratic governance and its social implications and socio-technical approaches. While smart urbanism as underpinned by big data offers seemingly seductive visions of the future, it also raises a number of concerns. The idea of big data being only as good as the modelling underlying its use exacerbates technocratic reductionism [194]. Technocratic governance is inherent in smart urbanism, and there is a lack of attention on what actually lies beyond the demarcations associated with what happens within city administrative boundaries. Kitchin [127] provides a critical reflection on the implications of big data and smart urbanism, examining technocratic governance and city development; corporatization of city governance and technological lock-ins; the politics of big urban data; buggy, brittle and hack-able cities; and the panoptic city. Kitchin [128] critically examines a number of urban data issues, including, in addition to corporatization and anticipatory governance, ownership, control, privacy and security, and technical challenges in the context of data-driven, networked urbanism and smart cities. Examining the forms, practices, and ethics of smart cities and urban science, Kitchin [129] gives particular attention to privacy, dataveillance and geo-surveillance, and such data uses as social sorting and anticipatory governance. With reference to the spread of COVID-19, Kitchin [130] questions the technical and practical efficacy of surveillance technologies, and examines their implications for civil liberties, governmentality, surveillance capitalism, and public health. The contentions the author challenges in this regard relate to the smartphone apps, facial recognition and thermal cameras, biometric wearables, smart helmets, drones, and predictive analytics technologies being rapidly developed and deployed to help tackle the spread of the so-called disease. The author points out that the rushed rollout of the surveillance technologies used for contact tracing, quarantine enforcement, social distancing/movement monitoring, and symptom tracking has been justified by the argument that they are vital to suppressing the virus and civil liberties have to be sacrificed for public health. In a nutshell, smart urbanism ignores social, political, cultural, economic, and historical contexts shaping urban life, thereby curtailing the opportunities for wider perspectives beyond technical systems and scientific processes. These are associated with the computational understanding of the city system that causes it to be destroyed and broken into pieces, and that reduces urban life to logic, calculative, and algorithmic rules and procedures to make the city objectively measurable, tractable, and controllable. Verrest and Pfeffer [215] critically engage with the rationale, methods, and implications of smart urbanism approaches within different urban contexts by distilling the missing dimensions in the current model of smart urbanism. The authors argue that the lack of consideration for “the urbanism” in smart urbanism is justified by the three dimensions that require further development to facilitate a comprehensive analysis of the implication of smart city policies for contemporary urban life, namely:

1. the acknowledgement that the urban is not confined to the administrative boundaries of a city;
2. the importance of local social-economic, cultural-political, and environmental contingencies in analyzing the development, implementation, and effects of smart city policies; and
3. the social-political construction of both the urban problems that the smart city policies aim to solve and the considered solutions.

Technocratic governance conceals those urban issues, conflicts, and controversies that cannot be represented by digital models and embedded in data analytics techniques [41,49,176]. Consequently, the outcome of supply oriented, technocratic governance of smart cities (e.g., [131,152]) seems to be highly unequal urban societies, characterized by unequal power relations, large gaps between those with access to information services or opportunities and those without, social exclusion, and unequal distributions of costs and benefits

([59,133,147]). This is due to putting much emphasis on the role of technology in collecting and analyzing data to extract useful knowledge in the form of applied intelligence to enhance government operations and automate urban system functions. However, while smart urbanism offers great potential to enhance the quality of life, it also leads to the marginalization of certain groups and create multiple divides between those who have access to smart applications and those who do not in relation to public transport, mobility, healthcare, education, utilities, and so on. Social exclusion issues in smart urbanism go beyond access to technology to include the distortion of the "reality of a city" and the particularities of localities, such as the history, feelings, concerns, knowledge, and trajectories of the existing urban communities [153]. In other words, while smart urbanism seems to highlight the importance of the quality of life at the discursive level, it tends to distort the individuality of the existing neighborhoods and strip off the particularities of the existing urban fabrics. For example, an urban fabric (e.g., inner city) created by multiple actor layers, incrementally developed with a diversity of building types, scales, and functions, is often seen as having the attributes of a more intense and livelier street lives [71,157]. In the context of the compact city, for example, the resilient urban properties that relate to increased diversity, networks, and increased number of agents through density and proximity are often seen in emergent urban areas that have developed incrementally through time [150,184]. To put it differently, emergent compact urban form, which is characterized by high density and diversity, facilitates incremental and individual micro interactions through time and space by multiple actors. It has the possibilities to change and adapt to create new emerged states as emergence is continuous and diversity is high.

There is a need for reshaping big data analytics in smart urbanism in ways that reconfigure the underlying epistemology to recognize the complex, dynamic, and contingent nature of cities. The basic argument is that smart urbanism is incompatible with the informal character of cities. As argued by Kitchin [[129], p. 11], cities need "to be framed as fluid, open, complex, multi–level, contingent, and relational systems that are full of culture, politics, competing interests and wicked problems and often unfold in unpredictable ways," instead of "being cast as bounded, knowable, and manageable systems that can be steered and controlled in mechanical, linear ways."

The technocratic governance challenges have prevented smart cities from achieving the expected outcomes [181]. The ideals of smart urbanism in seeking to take advantage from digital services require a "*reinvention of governance.*" Barns [[10], p. 6] In other words, there is a need for transformative and socio-technical approaches to smart governance ([57,118,169,219]) based on the IoT, big data analytics, and Artificial Intelligence for enhanced decision making processes and improved quality of life. Meijer and Bolívar [156] argue for new forms of human collaboration in smart governance to attain the desired outcomes as well as open and transparent processes. Jiang, Geertman and Witte [110] propose a framework for smart urban governance on the basis of three intertwined key components, namely spatial, institutional, and technological components. Their study reveals that the modes of smart governance varies remarkably depending on the urban issues identified in different urban contexts. It also indicates that a focus on substantive urban challenges enables defining appropriate modes of governance and developing dedicated technologies that can contribute to solving specific smart city challenges. It additionally highlights the importance of cultural, social, political, and economic contexts in analyzing interactions between the spatial, institutional, and technological components, thereby supporting a socio-technical approach to governing smart cities. These can be useful in enhancing the governance models of data-driven smart sustainable cities of the future.

4.3.3.4. Sustainability issues and conundrums. Critics have questioned the effectiveness of corporate-led, top-down software-enabled and technology-mediated urban developments that promise to make cities more environmentally sustainable, economically prosperous, as well as socially just (e.g., [30,152,226]). While there is a pervasive belief that new technologies will prevent social, economic, and environmental collapse, data-driven technological fixes show that the negative unintended consequences of science and technology are inherently unavoidable and unpredictable; sustainability improvements do not offer lasting solutions; and data-driven technologies, considering the current paradigm of economic development, do not promote sustainability but instead hasten collapse. Some authors dispute the net contribution of smart urbanism to sustainable urbanism (Gargiulo [82,217]).

As regards the social issues of sustainability, which have already been discussed earlier, Trencher [208] argues that while scholars critique the first-generation, corporate-led model of smart urbanism for failing to tackle people-oriented agendas and to authentically respond to the needs of residents, many point to the potential to move beyond narrow environmental and economic objectives to address and overcome social issues. The author claims that the techno-economic and centralized approach rather pertains to the first generation paradigm of smart urbanism, whose primary focus is on the diffusion of smart technologies for corporate interests. This however raises the question as to what trade-offs the so-called socially oriented smart cities are willing to make in order to contribute to the social aspect and quality of life over the economic benefits, including what the cost of these trade-offs will be. In fact, the current model of smart urbanism is being promoted and supported with significant investment of resources by numerous industrial actors [194]. The outcome is a very competitive market where the risk of the prevalence of stand-alone profit-making agendas becomes evident [182]. This is demonstrated by the huge investment being made by giant technology companies in R&D. The huge market of the smart city may well undermine economic development through the isolated ICT branding exercises of industrial actors [3], which has a clear bearing on socio-economic and socio-environmental sustainability. This potential risk becomes imminent when looking at the market growth of the smart city. Therefore, it is evident why the ICT industry and the private sector view the idea of the smart city as an opportunity to promote digital transformation [81], although the smart city is increasingly advocated by governments as the primary means to deliver urban sustainability.

The smart city is envisioned, particularly in Europe, as an urban environment where advanced technologies are deployed to solve urban sustainability problems. The European Commission has assigned a budget of nearly one billion euros on smart city projects for the period 2014–2020 [70]. Martin, Evans and Karvonen [151] provide a state-of-the-art, empirically informed analysis of smartness-sustainability, taking into consideration the established critiques of the policies and visions of the smart city alongside the actual experiences of its initiatives in Europe. The authors identify and test five tensions between the smart city and the goals of urban sustainability: (1) reinforcing neoliberal economic growth; (2) focusing on more affluent populations; (3) disempowering and marginalising citizens; (4) neglecting environmental protection; and (5) failing to challenge prevailing consumerist cultures. They found that the key to unlocking the forms of smart sustainable urbanism emphasizing environmental protection and social equity is to empower and engage citizens rather than merely reinforcing neoliberal forms of urbanism. Based on empirical research, Bibri [27] identifies, distills, and enumerates the key benefits, potentials, and opportunities of both smart cities and sustainable cities with respect to the three dimensions of sustainability, as well as the key institutional transformations needed to support the balancing of these dimensions. The author argues that the emerging data-driven technologies for sustainability as innovative niches are reconfiguring the socio-technical landscape of institutions, as well as providing insights to policymakers into pathways for strengthening existing institutionalized practices and competences and developing and establishing new ones. This is necessary for balancing and advancing the goals of sustainability and thus achieving a desirable future. The concept of the niche is taken from socio-technical transitions studies, which studies the processes through which innovations come about and are taken up in society more widely (e.g., [84,123]).

Furthermore, smart urbanism has been questioned concerning its actual impacts on ecological sustainability beyond energy efficiency technologies, integrated renewable solutions, environmental monitoring systems. De Jong et al. [63] argue for the potential psychological disconnection of inhabitants from the environment and the disruption of their relationship with nature as a result of their overexposure to technology. From another perspective, new technologies are associated with direct, indirect, and systemic effects. The direct effects of data-driven technologies on the environmental will exacerbate due to the increasing demand for their applications, products, and services. As to the indirect effects, which arise from the use of these advanced technologies, the operational functioning of data-driven smart sustainable cities requires a huge amount of energy to power ubiquitous sensors, data processing platforms, pervasive computing infrastructures, and wireless communication networks. The challenge of systemic effects is a real dilemma as it is unlikely to be a 'magic bullet' solution for their special conundrums. The systemic effects of data-driven technologies are the most complex of all given their dynamic, volatile, and unpredictable nature. In fact, the direct and indirect effects—which are relatively easy to model, analyze, and evaluate—have, up to the present time, been the focus of much of the research work that has been carried out on the link between technological innovation and environmental sustainability [30].

Despite the prevailing circumstances, the ideals of smart eco-urbanism have succeeded in triggering actions within the ecologically advanced nations around the world, and have recently become normalized as widely accepted ideas and approaches. By recognizing that the utopian rhetoric mobilized in the promotion of smart eco-urbanism may provide sensible grounds for useful critical evaluations, this model also proposes some ways in which it might be understood as a positive attribute [53]. Although some smart eco-city initiatives badge themselves as models for future sustainable development, they remain only sites of innovation and experimentation, attempting to accelerate the movement towards socio-technical sustainability transitions in the era of big data. It can be argued that the ability of smart eco-cities to achieve their utopian ambitions is limited by, as discussed above, the realities of technocratic governance, technocentric policies, and complex practices, in addition to operating within a profit-driven, neoliberal framework for planning and development. However, they can still provide a place to test new ideas (green technologies, sustainable waste management, data-driven smart solutions for energy efficiency and pollution reduction, etc.) and an ideal to aspire to. Historically, people have always moved to and preferred to live in eco-cities to improve the quality of their lives and environment, and again smart urbanism is being embraced to create eco-cities that make urban living more sustainable over the long run—in short, that last. Further, however, while the environmental considerations of sustainability remain a key driver of the smart eco–city projects, they are also mobilized in the pursuit of politico–economic goals. The plans and publicity materials of eco-city projects, notably those promoted in Asia and the Middle East as ambitious, technologically driven projects led by the public and private sector actors contain bold claims, attractive designs, ambitious targets, and innovative technologies to advertise their "eco-ness" [174].

4.3.3.5. Technocentricity and situatedness. We are in the midst of a new wave of enthusiasm for smart urbanism driven by the digital transformation and scientific revolution in the era of big data. However, one of the major challenges of smart urbanism in delivering the outcomes of sustainability lie in that its policies are characterized by technocentricity in terms of the application of data-driven scientism in sustainable urbanism, and that its practices involve contestations, negotiations, and contingencies. Urban big data are being used as the evidence base for formulating urban policies, plans, strategies, and programs, as well as for tracking their effectiveness and modelling and simulating future urban development projects. This may produce the kind of policy interventions that harm city operations and fail to live up to the promises claimed by smart urbanism. However, central to the concept of technocentricity is that scientific knowledge is required to monitor, evaluate, and improve performance. Accordingly, at the core of smart urbanism is the use of technology, which emphasizes and promotes the importance of technology or reflects trust in science. However, to what extent can science unveil the unique complexity and individuality of cities is a subject of much debate. The scientific and computational approaches wilfully ignore the role of politics, social norms, social structures, ideology, culture, as well as the metaphysical aspects of human life in shaping urban relations, planning, and governance [89]. Besides, the science of cities (e.g., [12]) is never really established, but smart urbanism is regarded as art and science [139]. Regardless, it is too atomizing, reductionist, mechanistic, deterministic, and parochial, collapsing diverse complex, multidimensional social structures and relationships to abstract data points and universal formulae and laws. Further, it is also questionable whether science can juxtapose the fragmentary conceptual underpinnings and conflicting ideological stances at the intersection of smart urbanism and sustainable urbanism.

From a philosophical perspective, (data-driven) scientific urbanism can be seen as a discourse of using scientific approaches and inquiries in urbanism inspired by big data science and analytics that historically quickly becomes fashionable and also quickly disappears. This relates to the theoretical perspective of situativity, which argues that knowledge, thinking, and learning are situated in experience. "All knowledge about reality begins with experience and terminates in it" ([69], p.164). Foucault [78] asserts that knowledge, whether theoretical or silently invested in practice, is fundamentally culturally contextual and historically situated. Situatedness as a theoretical position posits that human cognition is ontologically and functionally intertwined within environmental, social, and cultural factors. Knowledge is also a matter of episteme, the space of knowledge in which configurations are grounded on a set of claims, assumptions, premises, values, and truths basic to how the whole culture decides and justifies what is certain of. Episteme denotes a pre-cognitive space that determines "on what historical a priori, and in the element of what positivity, ideas could appear, sciences be established, experience be reflected in philosophies, rationalities be formed, only, perhaps, to dissolve and vanish soon afterwards" ([77], pp. xxi–xxii). Foucault's central argument is that different periods of history constitute different systems of thought or epistemological fields, and all social constructions of scientific knowledge fall under the episteme of a historical epoch. Bibri [22] examines the intertwined societal factors driving the materialization, success, expansion, and evolution of data-driven smart sustainable urbanism, and further critically discusses big data technology as social constructions in terms of their inherent flaws, limits, and biases. The author concludes that data–driven smart sustainable urbanism is shaped by, and also shape, socio–cultural and politico–institutional structures. And it will prevail for many years yet to come given the underlying transformational power of big data science and analytics, coupled with its legitimation capacity associated with the scientific discourse as the ultimate form of rational thought and the basis for legitimacy in knowledge production and policy–making.

5. Knowledge gaps in the area of data-driven smart sustainable cities

The area of data-driven smart sustainable cities is still in the early stages of its development, and therefore, there are many problems that need to be addressed, which offers a wide range of research opportunities. The knowledge gaps that need to be filled in this area are numerous and can be approached from a variety of perspectives, including, but are not limited to, theoretical, methodological, technical, scientific, evaluative, critical, empirical, futuristic, socio-political, economic, and institutional. They are identified to be critically important for the functioning, dissemination, success, and continuation of this rapidly evolving approach to urban planning and development. As such, they relate to many topics, of which the most relevant to this paper are listed in Table 9.

Table 9
Topics associated with the knowledge gaps in the area of data-driven smart sustainable cities.

• Conceptual and theoretical models for data-driven smart sustainable cities
• Analytical frameworks for data-driven smart sustainable cities
• Methodological approaches and technical methods for evaluating data-driven smart sustainable cities
• Visionary and strategic planning approaches for data-driven smart sustainable cities
• Economic, social, cultural, political, and ethical dimensions of data-driven smart sustainable cities
• Opportunities and challenges for designing and developing data-driven smart sustainable cities
• Built, infrastructural, social, political, and institutional transformations needed for promoting data-driven smart sustainable cities
• Socio-technical approaches to data-driven smart urban governance
• Integration of technocentric and human-centric policies for data-driven smart sustainable cities
• Societal and scientific challenges, opportunities, and barriers for using real-time data and analytics
• Assessment methods for measuring to what extent smartness enhances sustainability
• Comprehensive models for integrating sustainable city and smart city landscapes and strategies
• Complexity science and big data analytics for understanding urban complexity and sustainability
• Urban intelligence functions for monitoring and designing data-driven smart sustainable cities
• Urban computing approaches to timely decision-making processes for sustainability
• Horizontal information platforms and operations systems for data-driven smart sustainable cities
• Big data-enabled frameworks and architectures for data-driven smart sustainable cities
• AI-enabled data-driven smart sustainable urbanism processes
• Socially responsible artificial urban intelligence
• The potential risks of sensorization, hyper-connectivity, algorithmization, and datafication
• The negative implications of instrumenting the built environment on the environment
• Data-driven smart solutions for socio-economic sustainability of land use
• Green urban computing and urban sensing
• Advanced simulation models for dealing with new conceptions of data-driven smart sustainable cities as dynamically changing and adaptive environments
• Simulation models and optimization methods based on the integration of complexity science and sustainability science
• Models of data-driven smart sustainable cities functioning in real-time
• Multi-agent simulation for transport and traffic patterns
• New smart sustainable urbanism theories based on data-intensive science
• Data-driven short-term and joined planning for efficient designs and responses
• Sustainable energy production and consumption patterns analysis and prediction
• Big data analytics and GIS uses in waste management and transport inefficiency identification
• Data-driven sustainable energy demands analysis and prediction
• Data-driven land-use impact analysis
• Data-driven smart approaches to strategic planning of building energy retrofitting
• Modeling and simulation of emergent compact urban forms for future designs related to intensification.

6. Conclusion

Cities growing ever bigger and faster in terms of their populations and knowledge base lie at the core of data-driven smart sustainable cities of the future. Advanced ICT holds the key to a desirable future, and it will be most clearly demonstrated in sustainable cities. There are a number of innovations that have inspired the academic and practical endeavor of integrating sustainable cities and smart cities. In the era of big data, there is a growing perception that the centripetal movement of smart sustainable interests, ideas, and considerations in urban strategies, technological innovations, and institutional developments can have a significant impact on smart sustainable–induced processes of transformation in the primary operations, core practices, and central institutions of modern society.

This paper offered a comprehensive state-of-the-art literature review of the flourishing field of data-driven smart sustainable cities. Specifically, it endeavored to deliver a detailed analysis, critical evaluation, compelling synthesis, and well-worked discussion of the available research covering the topic of sustainable cities and smart cities in terms of their integration as the leading global paradigms of urbanism. In so doing, it answered several questions. Accordingly, it identified, described, and discussed the prevailing paradigms of sustainable urbanism and the emerging paradigms of smart urbanism, and also elucidated the way in which these paradigms relate to and complement each other in the context of sustainability. This is primarily meant to facilitate the integration and fusion of the different disciplinary fields underlying data-driven smart sustainable cities for the sheer purpose of generating the kind of interactional and unified knowledge needed to gain a broader understanding of and readily explore the topic on focus. Afterwards, this paper addressed compact cities and eco-cities as the central paradigms of sustainable urbanism in terms of their commonalities, deficiencies, shortcomings, and also the potential of smart solutions for increasing the benefits of social sustainability. Subsequently, it delved into the problems, issues, and challenges related to sustainable cities. Following that, it identified and enumerated the societal trends interplaying with sustainable cities and shaping and driving the emergence, materialization, expansion, and success of data-driven smart sustainable cities. Then it detailed and documented the potential role of the applied data-driven technology solutions for operational management and development planning in boosting and maintaining the performance of sustainable cities with respect to their contribution to the goals of sustainability. Lastly, this paper attempted to develop a critical understanding of smart urbanism, focusing on its potential risks and negative implications from a variety of perspectives and how and to what extent they affect sustainability in the context of data-driven smart sustainable urbanism.

This study corroborated that big data technologies will change sustainable urbanism in fundamental and irreversible ways, bringing new and innovative ways of understanding, planning, and managing sustainable cities. It revealed that the evolving development planning approaches and operational management mechanisms enabled by data-driven smart technologies are of paramount importance to boost and maintain the contribution of sustainable cities to the goals of sustainability in the face of urbanization. However, there are several critical questions to raise, including whether data-driven smart sustainable cities will become too technocentric and technocratic as they evolve, but also with regard to other aspects of social and environmental sustainability. Addressing these important contemporary concerns is of equal importance for achieving the desired outcomes of sustainability in the era of data-driven scientific urbanism.

The contribution of this review lies in providing a valuable reference for researchers, practitioners, and policymakers and the necessary material to inform them of the latest developments in the burgeoning field of data-driven smart sustainable cities. This review enables researchers and scholars to focus their work on the identified real–world opportunities and challenges pertaining to data-driven smart sustainable cities. Practitioners and policymakers can make use of the outcome of this review to identify the weaknesses of sustainable cities, especially compact cities and eco–cities, and to find more effective ways to address these weaknesses based on the emerging applied data-driven technology solutions offered by smart cities

It is hoped that this study will provide the grounding for further in-depth research in the emerging area of data-driven smart sustainable cities. Especially, a large part of the problems in this area is still not addressed, with many diverse critical aspects being fleshed out as part of the ongoing research endeavors. There are also many problems that have not been addressed well or appropriately by any of the existing research in the area of sustainable cities. This pertains particularly to how to integrate and balance the dimensions of urban sustainability based on big data technologies, and the multiple forms of integrating sustainable cities and smart cities at the technical and policy levels so as to make actual progress towards sustainability. There is a host of unexplored opportunities towards new approaches to data-driven smart sustainable urban planning and development. This is key to mitigating the extreme fragmentation and the weak connection pertaining to sustainable cities and smart cities as landscapes and approaches, respectively, through developing multiple visions of sustainable futures. Data-driven smart sustainable cities are a fertile area of interdisciplinary and transdisciplinary research involving numerous intriguing and multifaceted questions awaiting scholars and practitioners from across many city-related academic or scientific disciplines.

Author's contribution

The author read and approved the published version of the manuscript.

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References

[1] H. Ahvenniemi, A. Huovila, I. Pinto-Seppä, M. Airaksinen, What are the differences between sustainable and smart cities? Cities 60 (2017) 234–245.
[2] V. Albino, U. Berardi, R. Dangelico, Smart cities: definitions, dimensions, performance, and initiatives, J. Urban Technol. 22 (1) (2015) 3–21.
[3] Z. Allam, P. Newman, Redefining the smart city: culture, metabolism and governance, Smart Cities 1 (2018) 4–25, doi:10.3390/smartcities1010002.
[4] S. Al-Nasrawi, C. Adams, A. El-Zaart, A conceptual multidimensional model for assessing smart sustainable cities, J. Inf. Syst. Technol. Manag. 12 (3) (2015) 541–558.
[5] E. Al Nuaimi, H. Al Neyadi, M. Nader, J. Al-Jaroodi, Applications of big data to smart cities, J. Internet Serv. Appl. 6 (25) (2015) 1–15.
[6] S. Ameer, M.A. Shah, Exploiting big data analytics for smart urban planning, in: 2018 IEEE 88th Vehicular Technology Conference (VTC-Fall), Chicago, IL, USA, 2018, pp. 1–5.
[7] M. Angelidou, A. Psaltoglou, N. Komninos, C. Kakderi, P. Tsarchopoulos, A. Panori, Enhancing sustainable urban development through smart city applications, J. Sci. Technol. Policy Manag. 9 (2) (2017) 146–169.
[8] L. Anthopoulos, Understanding smart cities—a tool for smart government or an industrial trick?, Public Administration and Information Technology, 22, Springer Science+Business Media, New York, 2017.
[9] S.D. Arifwidodo, Exploring the effect of compact development policy to urban quality of life in Bandung, Indonesia, City Cult. Soc. 3 (2012) 303–311.
[10] S. Barns, Smart cities and urban data platforms: designing interfaces for smart governance, City Cult. Soc. 12 (March) (2018) 5–12.
[11] M. Batty, Big data, smart cities and city planning, Dialogues Hum. Geogr. 3 (3) (2013) 274–279.
[12] M. Batty, K.W. Axhausen, F. Giannotti, A. Pozdnoukhov, A. Bazzani, M. Wachowicz, et al., Smart cities of the future, Eur. Phys. J. 214 (2012) 481–518.
[13] J.H.P. Bay, S. Lehmann (Eds.), Growing Compact: Urban Form, Density and Sustainability, Routledge, Abingdon, UK; New York, NY, USA, 2017 ISBN 978-1-317-19085-1.
[14] U. Berardi, Sustainability assessment of urban communities through rating systems, Environ. Dev. Sustain. 15 (2013) 1573–1591, doi:10.1007/s10668-013-9462-0.
[15] Bertaud, A. (2001). 'Metropolis: a measure of the spatial organization of 7 large cities' (pp. 1–22). http://Alainbertaud.Com/; 10.1017/s037689291300012x.
[16] L.M.A. Bettencourt, The Uses of Big Data in Cities, Santa Fe Institute, Santa Fe, 2014.
[17] S.E. Bibri, Smart Sustainable Cities of the Future: the Untapped Potential of Big Data Analytics and Context Aware Computing for Advancing Sustainability, Springer, Berlin, 2018a.
[18] S.E. Bibri, The IoT for smart sustainable cities of the future: an analytical framework for sensor–based big data applications for environmental sustainability, Sustain. Cities Soc. 38 (2018b) 230–253.
[19] S.E. Bibri, A foundational framework for smart sustainable city development: theoretical, disciplinary, and discursive dimen- sions and their synergies, Sustain. Cities Soc. 38 (2018c) 758–794.
[20] S.E. Bibri, On the sustainability of smart and smarter cities in the era of big data: an interdisciplinary and transdisciplinary literature review, J. Big Data 6 (25) (2019a) 2–64.
[21] S.E. Bibri, The sciences underlying smart sustainable urbanism: unprecedented paradigmatic and scholarly shifts in light of big data science and analytics, Smart Cities 2 (2) (2019b) 179–213.
[22] S.E. Bibri, Data-driven smart sustainable urbanism: the intertwined societal factors underlying its materialization, success, expansion, and evolution, GeoJournal (2019c), doi:10.1007/s10708-019-10061-x.
[23] S.E. Bibri, Advances in smart sustainable urbanism: Data–driven and data–intensive scientific approaches to wicked problems, in: Proceedings of the 4th Annual International Conference on Smart City Applications, ACM, Oct 2–4, Casablanca, Morocco, 2019d.
[24] S.E. Bibri, Advances in the Leading Paradigms of Urbanism and Their Amalgamation: Compact Cities, Eco–cities, and Data–Driven Smart Cities, vol 2020, Springer Nature Switzerland AG, Cham, 2020a.
[25] S.E. Bibri, The eco-city and its core environmental dimension of sustainability: green energy technologies and their integration with data-driven smart solutions, Energy Inf. 3 (4) (2020b).
[26] S.E. Bibri, Compact urbanism and the synergic potential of its integration with data-driven smart urbanism: an extensive interdisciplinary literature review, J Land Use Policy 97 (2020c) 1–20.
[27] S.E. Bibri, A novel model for data-driven smart sustainable cities of the future: the institutional transformations required for balancing and advancing the three goals of sustainability, Energy Inf. 4 (2021a) 4, doi:10.1186/s42162-021-00138-8.
[28] S.E. Bibri, The core academic and scientific disciplines underlying data-driven smart sustainable urbanism: an interdisciplinary and transdisciplinary framework, J. Comput. Urban Sci. (2021b) (in Press).
[29] S.E. Bibri, Data-driven smart sustainable cities of the future: urban computing and intelligence for strategic, short-term, and joined-up planning, Comput. Urban Sci. (2021c) (In Press).
[30] S.E. Bibri, J. Krogstie, On the social shaping dimensions of smart sustainable cities: a study in science, technology, and society, Sustain. Cities Soc. 29 (2016) 219–246.
[31] S.E. Bibri, J. Krogstie, ICT of the new wave of computing for sustainable urban forms: their big data and context-aware augmented typologies and design concepts, Sustain. Cities Soc. 32 (2017a) 449–474.
[32] S.E. Bibri, J. Krogstie, ICT of the new wave of computing for sustainable urban forms: their big data and context-aware augmented typologies and design concepts, Sustain. Cities Soc. 32 (2017b) 449–474.
[33] S.E. Bibri, J. Krogstie, The core enabling technologies of big data analytics and context–aware computing for smart sustainable cities: A Review and synthesis, J. Big Data 4 (38) (2017c) 1–50.
[34] S.E. Bibri, J. Krogstie, A scholarly backcasting approach to a novel model for smart sustainable cities of the future: strategic problem orientation, City Territory Archit. 6 (3) (2019) 1–27.
[35] S.E. Bibri, J. Krogstie, Smart eco-city strategies and solutions for sustainability: the cases of royal seaport. Stockholm, Western Harbor, Malmö, Sweden, Urban Sci. 4 (1) (2020a) 1–42.
[36] S.E. Bibri, J. Krogstie, The emerging data–driven smart city and its innovative applied solutions for. sustainability: the cases of London and Barcelona, Energy Inf. 3 (2020b) 5.
[37] S.E. Bibri, J. Krogstie, Environmentally data-driven smart sustainable cities: applied innovative solutions for energy efficiency, pollution reduction, and urban metabolism, Energy Inf. 3 (2020c) 29.
[38] S.E. Bibri, J. Krogstie, Data-driven smart sustainable cities of the future: a novel model of urbanism and its core dimensions, strategies, and solutions, J. Futures Stud. 25 (2) (2020d) 77–94.
[39] S.E. Bibri, J. Krogstie, A novel model for data-driven smart sustainable cities of the future: a strategic roadmap to transformational change in the era of big data, Future Cities Environ. 7 (1) (2021) 3 1–25.
[40] S.E. Bibri, J. Krogstie, M. Kärrholm, Compact city planning and development: emerging practices and strategies for achieving the goals of sustainability, Dev Built Environ 4 (2020) 1–2.
[41] O. Bina, A. Inch, L. Pereira, Beyond techno-utopia and its discontents: on the role of utopianism and speculative fiction in shaping alternatives to the smart city imaginary, Futures 115 (January) (2020) 102475.

[42] M. Böhlen, H. Frei, Ambient intelligence in the city: overview and new perspectives, in: H. Nakashima, H. Aghajan, J.C. Augusto (Eds.), Handbook of Ambient Intelligence and Smart Environments, Springer, New York, 2009, pp. 911–938.
[43] G. Bramley, S. Power, Urban form and social sustainability: the role of density and housing type, Environ. Plan. B 36 (1) (2009) 30–48.
[44] E. Burton, The compact city: just or just compact? A preliminary analysis, Urban Stud. 37 (11) (2000) 1969–1920.
[45] H. Bulkeley, V. Castán Broto, Government by experiment? Global cities and the governing of climate change, Trans. Inst. Br. Geogr. 38 (3) (2013) 361–375.
[46] E. Burton, The Compact City and Social Justice , a Paper Presented to the Housing Studies Association Spring Conference, Housing, Environment and Sustainability. University of York, 2001.
[47] E. Burton, Measuring urban compactness in UK towns and cities, Environ. Plan. B 29 (2002) 219–250.
[48] S. Campbell, Green cities, growing cities, just cities? Urban planning and the contradictions of sustainable development, J. Am. Plan. Assoc. 62 (3) (1996) 296–312.
[49] P. Cardullo, R. Kitchin, Being a 'citizen' in the smart city: up and down the scaffold of smart citizen participation in Dublin, Ireland, GeoJournal 84 (1) (2019) 1–13.
[50] P. Calvo, The ethics of Smart City (EoSC): moral implications of hyperconnectivity, algorithmization and the datafication of urban digital society, Ethics Inf. Technol. 22 (2020) 141–149, doi:10.1007/s10676-019-09523-0.
[51] A. Caragliu, C. Del Bo, P. Nijkamp, 'Smart Cities in Europe' (series research memoranda 0048), VU University Amsterdam, Faculty of Economics, Business Administration and Econometrics, Amsterdam, 2009.
[52] A.J. Collins, C.J.M.B. Fauser, Balancing the strengths of systematic and narrative reviews, Hum. Reprod. Update 11 (2) (2005) 103–104.
[53] R. Cowley, Science fiction and the smart eco–city, in: The Society for the History of Technology Annual Meeting, Singapore, 2016, pp. 22–26.
[54] K. Crawford, J. Schultz, Big data and due process: toward a framework to redress predictive privacy harms, Boston Coll. Law Rev. 55 (2014) 93–128.
[55] F. Cugurullo, Exposing smart cities and eco-cities: Frankenstein urbanism and the sustainability challenges of the experimental city, Environ. Plan. A Econ. Space 50 (2016) 73–92.
[56] F. Cugurullo, Urban artificial intelligence: from automation to autonomy in the Smart City, Front. Sustain. Cities 2 (2020) 38.
[57] U.L. Dano, A.L. Balogun, I.R. Abubakar, Y.A. Aina, Transformative urban governance: Confronting urbanization challenges with geospatial technologies in Lagos, Nigeria, GeoJournal 85 (August) (2019) 1–18.
[58] G.B. Dantzing, T.L. Saaty, Compact City: a Plan for a Livable Urban Environment, W.H. Freeman, San Francisco, 1973.
[59] A. Datta, New urban utopias of postcolonial India: 'Entrepreneurial urbanization' in Dholera smart city, Gujarat. Dialogues in Human Geography (2015) (in press). Available at: http://eprints.whiterose.ac.uk/83074/.
[60] T.O.H. Davies, K.L. Crombie, What is a Systematic Review, 2003 Retrieved February 14, 2006 from http://www.evidence-based-medicine.co.uk/What_is_series.html .
[61] R. Durack, Village vices: The contradiction of new urbanism and sustainability, Places 14 (2) (2001) 64–69.
[62] D. Li, C. Lin, W. Gao, Z. Chen, Z. Wang, G. Liu, Capsules TCN Network for Urban Computing and Intelligence in Urban Traffic Prediction, Wireless Communications and Mobile Computing, 2020 Volume 2020, Article ID 6896579, 15 pages, doi:10.1155/2020/6896579.
[63] M. De Jong, S. Joss, D. Schraven, C. Zhan, M. Weijnen, Sustainable- smart-resilient-low carbon-eco-knowledge cities; making sense of a multitude of concepts promoting sustainable urbanization, J. Clean. Prod. 109 (2015) 25–38, doi:10.1016/j.jclepro.2015.02.004.
[64] N. Dempsey, M. Jenks, The future of the compact city, Built. Environ. 36 (1) (2010) 116–121.
[65] N. Dempsey, et al., Elements of urban form, Dimensions of the Sustainable City, 2010, pp. 21–52.
[66] M. Dornhöfer, C. Weber, J. Zenkert, M. Fathi, A data-driven smart city transformation model utilizing the green knowledge management cube, in: 2019 IEEE International Smart Cities Conference (ISC2), Casablanca, Morocco, 2019, pp. 691–696, doi:10.1109/ISC246665.2019.9071703.
[67] M.H. Echenique, A.J. Hargreaves, G. Mitchell, A. Namdeo, Growing cities sustainably: does urban form really matter? J. Am. Plan. Assoc. 78 (2012) 121–137.
[68] Ecocity BuildersInternational Ecocity Standards, 2010 http://ecocitybuilders.org/IESproject.html.
[69] A. Einstein, On the method of theoretical physics, Philos. Sci. 2 (1934) 163–169.
[70] EIP-SCCStrategic Implementation Plan, 2013 Available online at: http://ec.europa.eu/eip/smartcities/files/sip_final_en.pdf .
[71] H.-J. Eom, G.-H. Cho, Exploring thresholds of built environment characteristics for walkable communities: empirical evidence from the Seoul metro-politan area, Transp. Res. Part D 40 (2015) 76–86.
[72] H. Estiri, Energy planning in a big data era: a theme study of the residential sector, in: P. Thakuriah, N. Tilahun, M. Zellner (Eds.), Seeing Cities Through Big Data, Springer Geography. Springer, Cham, 2017, doi:10.1007/978-3-319-40902-3_13.
[73] European CommissionSmart Cities, 2019 Available online at: https://ec.europa.eu/info/eu-regional-and-urban-development/topics/cities-and-urban-development/city-initiatives/smart-cities_en (accessed August 19, 2019).
[74] J. Evans, A. Karvonen, R. Raven, The Experimental City, London, Routledge, 2016.
[75] EvergreenHow to be Smart(er) in Mid-Sized Cities in Ontario, 2018 Available online at: https://www.evergreen.ca/downloads/pdfs/2018/tech-and-data-msc.pdf (accessed August 19, 2019).
[76] D. Farr, Sustainable Urbanism, Wiley, 2008.
[77] M. Foucault, The Order of Things: an Archaeology of the Human Sciences, Random House, New York, 1970.
[78] M. Foucault, The Archaeology of Knowledge, Routledge, London, 1972.
[79] M. Foucault, Discipline and Punish: the Birth of the Prison, Pantheon Books, New York, 1977.
[80] H. Frey, Designing the City: Towards a More Sustainable Urban Form, Taylor & Francis, London, UK; New York, NY, USA, 1999 ISBN 978-0-419-22110-4.
[81] Future Cities CatapultSMART CITY STRATEGIES. A Global Review, 2017 [Online]. Available: https://futurecities.catapult.org.uk/wp-content/uploads/2017/11/GRSCS-Final-Report.pdf [Accessed 19/08/2019].
[82] G. Morelli, W. V., M.P. C., E.M. Van Bueren, I. Wenzler, G.A. De Reuver, L. Salvati, Towards intelligently-sustainable cities? From intelligent and knowledge city programmes to the achievement of urban sustainability, TEMA J. Land Use Mobil. Environ. 6 (2013) 73–86, doi:10.6092/1970-9870/1496.
[83] M. Gebresselassiea, T.M. Sanchez, Smart' tools for socially sustainable transport, International Journal of Urban Sciences 2 (2018) 45.
[84] F.W. Geels, Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, Res. Policy 31 (2002) 1257–1274.
[85] D. Gianni, A. D'Ambrogio, A. Tolk, Modeling and Simulation-Based 3015 Systems Engineering Handbook, first ed., CRC Press, 2014.
[86] R. Giffinger, F. Ch, H. Kramar, R. Kalasek, N. Pichler-Milanovic, E. Meijers, Smart Cities—Ranking of European Medium-Sized Cities, Centre of Regional Science (SRF), Vienna University of Technology, 2007 Viewed 2 Feb 2013.
[87] L. Gitelman, Raw Data" is an Oxymoron, MIT Press, Cambridge, 2013.
[88] A.Y. Grinberger, M. Lichter, D. Felsenstein, Dynamic agent based simulation of an urban disaster using synthetic big data, in: P. Thakuriah, N. Tilahun, M. Zellner (Eds.), Seeing Cities Through Big Data, Springer Geography. Springer, Cham, 2017, doi:10.1007/978-3-319-40902-3_20.
[89] D. Harvey, Social Justice and the City, Edward Arnold, London, UK, 2009.
[90] F. Harvey, Green Vision: The Search for the Ideal Eco–City, London Financ Times, 2011.
[91] I.A.T. Hashem, V. Chang, N.B. Anuar, K. Adewole, I. Yaqoob, A. Gani, et al., The role of big data in smart city, Int. J. Inf. Manag. 36 (2016) 748–758.
[92] F. Hayek, The results of human action but not of human design, New Studies 3022 in Philosophy, Politics, Economics, University of Chicago 3023 Press, Chicago, 1978, pp. 96–105.
[93] H. Kim, H. Choi, H. Kang, J. An, S. Yeom, T. Hong, A systematic review of the smart energy conservation system: From smart homes to sustainable smart cities, Renew. Sustain. Energy Rev. 140 (2021) 110755.
[94] J. Heinonen, S. Junnila, Implications of urban structure on carbon consumption in metropolitan areas, Environ. Res. Lett. 6 (1) (2011) 014018.
[95] H. Hofstad, Compact city development: high ideals and emerging practices, Eur. J. Spat. Plan. (2012) 1–23.
[96] M. Höjer, S. Wangel, Smart sustainable cities: definition and challenges, in: L. Hilty, B. Aebischer (Eds.), ICT Innovations for Sustainability, Springer, Berlin, 2015, pp. 333–349.
[97] R.G. Hollands, Will the real smart city please stand up? City Anal. Urban Trends Cult. Theory Policy Action 12 (3) (2008) 303–320.
[98] R.G. Hollands, Critical interventions into the corporate smart city, Camb. J. Regions Econ. Soc. 8 (2015) 61–77, doi:10.1093/cjres/rsu011.
[99] L. Holmstedt, N. Brandt, K.H. Robert, Can stockholm royal seaport be part of the puzzle towards global sustainability? From local to global sustainability using the same set of criteria, J. Cleaner Prod. 140 (2017) 72–80.
[100] T. Hatuka, H. Zur, From smart cities to smart social urbanism: a framework for shaping the socio-technological ecosystems in cities, Telematics Inform. 55 (101430) (2020).
[101] C. Ihlebæk, P. Næss, H. Stefansdottir, Are compact cities a threat to public health? European Planning Studies (IF 2.226), 2020, doi:10.1080/09654313.2020.1775790.
[102] International Telecommunications Union (ITU), Agreed definition of a smart sustainable cityFocus Group on Smart Sustainable Cities, SSC-0146 version Geneva, 2014 5–6 Mar.
[103] International Telecommunication UnionSmart Sustainable Cities: an Analysis of Definitions, TU-T Focus Group on Smart Sustainable Cities, 2016.
[104] Y.R. Jabareen, Sustainable urban forms: their typologies, models, and concepts, J. Plan. Educ. Res. 26 (2006) 38–52.
[105] M. Jenks, The acceptibility of urban intensification, in: K. Williams, E. Burton, M. Jenks (Eds.), Achieving Sustainable Urban Form, Routledge, London, UK; New York, NY, USA, 2000, pp. 242–250. ISBN 978-0-419-24450-9.
[106] M. Jenks, E. Burton, K. Williams, A sustainable future through the compact city? Urban intensification in the United Kingdom, Environ. Des. 1 (1) (1996a) 5–20.
[107] M. Jenks, E. Burton, K. Williams (Eds.), The Compact City: a Sustainable Urban Form, E&FN Spon Press, London, 1996b.
[108] M. Jenks, N. Dempsey, Future Forms and Design for Sustainable Cities, Oxford Elsevier, 2005.
[109] , Dimensions of the Sustainable City, 2, in: M. Jenks, C. Jones (Eds.), Springer, London, 2010.
[110] H. Jiang, S. Geertman, P. Witte, Smart urban governance: an alternative to technocratic "smartness, GeoJournal (2020), doi:10.1007/s10708-020-10326-w.
[111] S.G. Ji, Y. Zheng, T.R. Li, Urban sensing based on human mobility, in: Proceedings of the 18th ACM International Conference on Ubiquitous Computing, (UbiComp 2016), 2016, pp. 1040–1051.
[112] K. Jones, Mission drift in qualitative research, or moving toward a systematic review of qualitative studies, moving back to a more systematic narrative review, Qual. Rep. 9 (1) (2004) 95–112.

[113] C. Jones, C. Macdonald, Sustainable urban form and real estate markets, in: European Real Estate Conference, Milan, 2004, pp. 2–5.
[114] C. Jones, M. Jenks, G. Bramley, Complementarities and contradictions, in: M. Jenks, C. Jones (Eds.), Dimensions of the Sustainable City (volume 2), SpringerLink, London, 2010a, pp. 239–256.
[115] S. Joss, Eco–cities—a global survey 2009, WIT Trans. Ecol. Environ. 129 (2010) 239–250.
[116] S. Joss, Eco-cities: the mainstreaming of urban sustainability; key characteristics and driving factors, Int. J. Sustain. Dev. Plan. 6 (3) (2011) 268–285.
[117] S. Joss, R. Cowley, D. Tomozeiu, Towards the ubiquitous eco-city: an analysis of the internationalisation of eco-city policy and practice, J. Urban Res. Pract. 76 (2013) 16–22.
[118] S. Joss, F. Sengers, D. Schraven, F. Caprotti, Y. Dayot, The smart city as global discourse: storylines and critical junctures across 27 cities, J. Urban Technol. 26 (1) (2019) 3–34.
[119] K. Kaido, Urban densities, quality of life and local facility accessibility in principal Japanese cities, in: M. Jencks, N. Dempsey (Eds.), Future Forms and Design for Sustainable Cities, Architectural Press, Oxford, 2005, pp. 311–338.
[120] Z.H. Khan, T.A. Gulliver, A macroscopic traffic model for traffic flow harmonization, Eur. Transp. Res. Rev. 10 (2) (2018).
[121] M. Kärrholm, The scaling of sustainable urban form: some scale—related problems in the context of a Swedish urban landscape, Eur. Plan. Stud. 19 (1) (2011) 97–112.
[122] Karvonen, van Heur, Urban laboratories: Experiments in reworking cities, Int. J. Urban Region. Res. 38 (2014) 379–392.
[123] R. Kemp, et al., Transition management as a model for managing processes of co-evolution towards sustainable development, Int. J. Sustain. Dev. World Ecol. 14 (2007) 1–15.
[124] J.R. Kenworthy, The eco-city: ten key transport and planning dimensions for sustainable city development, Environ. Urbaniz. 18 (1) (2006) 67–85.
[125] J.R. Kenworthy, Urban Transport and Eco–Urbanism: a Global Comparative Study of Cities With a Special Focus on Five Larger Swedish Urban Regions MDPI, Urban Science, 2019.
[126] M. Kirkevold, lntegrative nursing research-an important strategy to further the development of nursing science and Practice, J. Adv. Nurs. 25 (1997) 977–984.
[127] R. Kitchin, The real-time city? Big data and smart urbanism, Geo J. 79 (2014) 1–14.
[128] R. Kitchin, Data–Driven, Networked Urbanism. The Programmable City Working Paper, Maynooth University, County Kildare, 2015.
[129] R. Kitchin, The ethics of smart cities and urban science, Philos. Trans. R. Soc. A 374 (2016) 20160115.
[130] R. Kitchin, Civil liberties or public health, or civil liberties and public health? Using surveillance technologies to tackle the spread of COVID-19, Space Polity (2020) 1–20.
[131] R. Kitchin, T.P. Lauriault, G. McArdle, Knowing and governing cities through urban indicators, city benchmarking and real-time dashboards, Reg. Stud. Reg. Sci. 2 (1) (2015) 6–28.
[132] R. Kotharkar, P.N. Bahadure, A. Vyas, Compact city concept: its relevance and applicability for planning of Indian cities, in: 28th International PLEA Conference (November)., 2014.
[133] A. Kramers, J. Wangel, M. Höjer, Governing the smart sustainable city: the case of the Stockholm Royal Seaport, in: Proceedings of ICT for Sustainability 2016, 46, Atlantis Press, Amsterdam, 2016, pp. 99–108.
[134] A. Kumar, A. Prakash, The role of big data and analytics in smart cities, Int. J. Sci. Res. 6 (14) (2016) 12–23.
[135] W. Kuitert, Urban landscape systems understood by geo–history map overlay, J. Landsc. Archit. 8 (1) (2013) 54–63.
[136] B. Kühne, K. Heidel, How could smart cities use data? – Towards a taxonomy of data-driven smart city projects" (2021), in: Wirtschaftsinformatik 2021 Proceedings, 1, 2021.
[137] K. Kourtit, P. Nijkamp, Smart cities in the innovation age, Innov. Eur. J. Soc. Sci. Res. 25 (2012) 93–95, doi:10.1080/13511610.2012.660331.
[138] J.D. Landis, Modeling urban systems, in: R. Weber, R. Crane (Eds.), The Oxford Handbook of Urban Planning, Oxford University Press, Oxford, England, 2012, pp. 323–350. ISBN 978-0-19-537499-5.
[139] R. LeGates, N.J. Tate, R. Kingston, Spatial thinking and scientific urban planning, Environ. Plan. B 36 (5) (2009) 763–768.
[140] M. Lehtonen, The environmental-social interface of sustainable development: capabilities, social capital, institutions, Ecol. Econ. 49 (2004) 199–214, doi:10.1016/j.ecolecon.2004.03.019.
[141] S.B. Letaifa, How to strategize smart cities: revealing the SMART model, J. Bus. Res. 68 (2015) 1414–1419, doi:10.1016/j.jbusres.2015.01.024.
[142] M. Lindsay, K. Williams, C. Dair, Is there room for privacy in the compact city? Built Environ. 36 (2010) 28–46.
[143] H.K. Lim, J-H. Kain, Compact cities are complex, intense and diverse but: can we design such emergent urban properties? Urban Plan 1 (1) (2016) 95.
[144] W. Liu, P. Cui, J.K. Nurminen, Jingdong Wang Special issue on intelligent urban computing with big data., Mach. Vis. Appl. 28 (2017) 675–677, doi:10.1007/s00138-017-0877-8.
[145] Y. Lu, A. Scott, J. Kim, C.B. Curi, J. McCarty, A. Pardy, R. Kellett, Integration of an energy– economy model with an urban energy model, Build. Cities 2 (1) (2021) 114–133 http://doi.org/10.5334/bc.71.
[146] A. Luque-Ayala, S. Marvin, Developing a critical understanding of smart urbanism? Urban Stud. 52 (12) (2015) 2105–2116, doi:10.1177/0042 098015577319.
[147] A. Luque, C. McFarlane, S. Marvin, Smart urbanism, in: M Hodson, S Marvin (Eds.), After Sustainable Cities?, Routledge, London, 2014, p. 74.
[148] C.R. Lynch, V.J. Del Casino Jr, Smart spaces, information processing, and the question of intelligence, Ann. Am. Assoc. Geogr. 110 (2) (2020) 382–390.
[149] P.J. Marcotullio, Towards Sustainable Cities: East Asian, North American and European Perspectives on Managing Urban Regions, Routledge, New York, 2017.
[150] S. Marshall, Planning, design and the complexity of cities, in: J. Portugali, H. Meyer, E. Stolk, E. Tan (Eds.), Complexity Theories of Cities Have Come of Age, Springer, Berlin, Heidelberg, 2012, pp. 191–206.
[151] C.J. Martin, J. Evans, A. Karvonen, Smart and sustainable? Five tensions in the visions and practices of the smart-sustainable city in Europe and North America, Technol. Forecast. Soc. Change 133 (2018) 269–278.
[152] S. Marvin, A. Luque-Ayala, C. McFarlane (Eds.), Smart Urbanism: Utopian Vision or False Dawn?, Routledge, London & New York, 2015.
[153] C. McFarlane, O. Söderström, On alternative smart cities: from a technology-intensive to a knowledge-intensive smart urbanism, City 21 (2017) 312–328 doi:10.1080/13604813.2017.13 27166.
[154] McKinseySmart Cities: Digital Solutions for a More Livable Future. McKinsey Global Institute, 2018 Available online at https://www.mckinsey.com/~/media/mckinsey/industries/capital%20projects%20and%20infrastructure/our%20insights/smart%20cities%20digital%20solutions%20for%20a%20more%20livable%20future/mgi-smart-cities-full-report.ashx (accessed August 19, 2019).
[155] M.K. Sutherland, M.E. Cook, Data-driven smart cities: a closer look at organizational, technical and data complexities, in: Proceedings of the 18th Annual International Conference on Digital Government Research (dg.o '17), Association for Computing Machinery, New York, NY, USA, 2017, pp. 471–476, doi:10.1145/3085228.3085239.
[156] A. Meijer, M.P.R Bolívar, Governing the smart city: A review of the literature on smart urban governance, International Review of Administrative Sciences 82 (2) (2016) 392–408.
[157] K.R. Merlino, Urban Grain and the Vibrancy of Older Neighbourhoods: Metrics and Measures. Considering Research: Reflecting Upon Current Themes in Architectural Research, Lawrence Tech University, Detroit, USA, 2011, pp. 477–488.
[158] M. Mostafavi, G. Doherty, Ecological Urbanism, Lars Muller, Switzerland, 2010.
[159] K. Mouratidis, Is compact city livable? The impact of compact versus sprawled neighbourhoods on neighbourhood satisfaction, Urban Stud. 55 (2018) 2408–2430.
[160] M. Neuman, The compact city fallacy, J. Plan. Educ. Res. 25 (2005) 11–26.
[161] T. Nam, T.A. Pardo, Conceptualizing smart city with dimensions of technology, people, and institutions, in: Proceedings of the 12th Annual International Conference on Digital Government Research, 2011.
[162] P. Neirotti, A. De Marco, A.C. Cagliano, G. Mangano, F. Scorrano, Current trends in smart city initiatives—some stylized facts, Cities 38 (2014) 25–36.
[163] K. Nikitin, N. Lantsev, A. Nugaev, A. Yakovleva, Data-Driven Cities: From Concept to Applied Solutions. Pricewater- houseCoopers (PwC), 2016 http://docplayer.net/50140321-From-concept-to-applied-solutions-data-driven-cities.html.
[164] N. Noori, T. Hoppe, M. de Jong, Classifying pathways for Smart City development: comparing design, governance and implementation in Amsterdam, Barcelona, Dubai, and Abu Dhabi, Sustainability 12 (2020) 4030.
[165] OECD, Compact city policies: a comparative assessment, OECD', OECD Green Growth Studies, 2012, pp. 123–158, doi:10.1787/9789264167865-en.
[166] P. Qin, R. Nishii, Statistical prediction of Dst index by solar wind data and t-distributions, IEEE Trans. Plasma Sci. 43 (11) (2015) 3908–3915.
[167] O. Pasichnyi, F. Levihn, H. Shahrokni, J. Wallin, O. Kordas, Data-driven strategic planning of building energy retrofitting: The case of Stockholm, J Clean Prod 233 (2019) 546–560.
[168] I.S. Pandis, N. Brandt, The development of a sustainable urban district in Hammarby Sjöstad, Stockholm, Sweden? Environ. Dev. Sustain. 13 (6) (2011) 1043–1064.
[169] G.V. Pereira, P. Parycek, E. Falco, R. Kleinhans, Smart governance in the context of smart cities: a literature review, Inf. Polity 23 (2) (2018) 143–162.
[170] C. Perera, Y. Qin, J.C. Estrella, S. Reiff-Marganiec, A.V. Vasilakos, Fog computing for sustainable smart cities: a survey, ACM Comput. Surv. 50 (3) (2017) 1–43.
[171] A.M. Pozdniakova, Smart city strategies "London-Stockholm-Vienna-Kyiv": in search of common ground and best practices, Acta Innov. 27 (2018) 31–45.
[172]´ N. Petrovic,´ Đ. Kocic, Data-driven framework for energy-efficient smart cities, J. Electr. Eng. 17 (2020) 41–63.
[173] I. Prigogine, The End of Certainty, The Free Press, New York, 1997.
[174] E. Rapoport, Utopian visions and real estate dreams: the eco-city past, present and future, Geogr. Compass 8 (2014) 137–149.
[175] E. Rapoport, A.L. Vernay, Defining the eco–city: a discursive approach, in: In: Paper Presented at the Management and Innovation for a Sustainable Built Environment Conference, International Eco–Cities Initiative, The Netherlands, Amsterdam, 2011, pp. 1–15.
[176] M.M. Rathore, A. Awais, P. Anand, R. Seungmin, Urban planning and building smart cities based on the Internet of Things using Big Data analytics, Comp. Netw. 101 (2016) 63–80.
[177] E. Reclus, L'homme et la terre, Tome Cinquième, Librarie universelle, Paris, 1905.
[178] R. Register, Ecocity Berkeley, North Atlantic Books, Berkeley, CA, 1987.
[179] H.W.J. Rittel, M.M. Webber, Dilemmas in a general theory of planning, Pol. Sci. 4 (1973) 155–169.
[180] M. Roseland, Dimensions of the eco–city, Cities 14 (4) (1997) 197–202.
[181] R.W.S. Ruhlandt, The governance of smart cities: a systematic literature review, Cities 81 (November) (2018) 1–23.
[182] J. Sadowski, Selling Smartness Visions and Politics of the Smart City (Doctoral dissertation), Arizona State University, 2016.
[183] S. Sarkar, S. Chawla, S. Ahmad, et al., Effective urban structure inference from traffic flow dynamics, IEEE Trans. Big Data 3 (2) (2017) 181–193.

[184] J. Scheurer, Compact City Policy: How Europe Re- Discovered its History and Met Resistance. The Urban Reinventors, 2, 2007 Retrieved from http://www.urbanreinventors.net/2/scheurer/scheurer-urbanreinventors.pdf .
[185] A.J. Sinaeepourfard, XM-B. Garcia, E. Marín-Tordera, J. Cirera, G. Grau, F. Casaus, Estimating Smart City sensors data generation current and future data in the City of Barcelona, in: Proceedings of Conference: the 15th IFIP Annual Mediterranean Ad Hoc Networking Workshop, 2016.
[186] H. Shahrokni, F. Levihn, N. Brandt, Big meter data analysis of the energy efficiency potential in Stockholm's building stock, Energy Build. 78 (2014a) 153–164.
[187] H. Shahrokni, D. Lazarevic, N. Brandt, Smart urban metabolism: towards a real—time understanding of the energy and material flows of a city and its citizens, J. Urban Technol. 22 (1) (2015) 65–86.
[188] M.N.I. Sarker, M.N. Khatun, G.M. Alam, M.S. Islam, Big Data Driven Smart City: Way to Smart City Governance, in: 2020 International Conference on Computing and Information Technology (ICCIT-1441), Tabuk, Saudi Arabia, 2020, pp. 1–8, doi:10.1109/ICCIT-144147971.2020.9213795.
[189] D. Shin, Ubiquitous city: urban technologies, urban infrastructure and urban informatics, J. Inf. Sci. 35 (5) (2009) 515–526.
[190] M.R. Shirazi, R. Keivani, Social sustainability of compact neighbourhoods evidence from London and Berlin, Sustainability 13 (4) (2021) 2340, doi:10.3390/su13042340.
[191] C.E. Seçkiner Bingöl, Citizen participation in smart sustainable cities, in: E.Akman. Babaoğlu, O. Kulaç (Eds.), Handbook of Research on Global Challenges for Improving Public Services and Government Operations, IGI Global, 2021 (pp. 443–463), doi:10.4018/978-1-7998-4978-0.ch023.
[192] B.N. Silva, M. Khan, C. Jung, J. Seo, D. Muhammad, J. Han, Y. Yoon, K. Han, Urban Planning and Smart City Decision Management Empowered by Real-Time Data Processing Using Big Data Analytics, Sensors 18 (2018) 2994, doi:10.3390/s18092994.
[193] E.R. Slavin, Best-evidence synthesis: an alternative to meta-analytic and traditional reviews, Educ. Res. 15 (9) (1986) 5–11.
[194] O. Söderström, T. Paasche, F. Klauser, Smart cities as corporate storytelling, City 18 (2014) 307–320.
[195] Y. Song, G. Knaap, Measuring urban form, J. Am. Plan. Assoc. 70 (2) (2004) 210–225 ISSN: 1387–3679.
[196] H. Song, R. Srinivasan, T. Sookoor, S. Jeschke, Smart Cities: Foundations, Principles, and Applications, Wiley, NJ, 2017.
[197] P. Späth (Ed.), Smart –Eco Cities in Germany: Trends and City Profiles, University of Exeter (SMART –ECO Project), Exeter, 2017.
[198] F.R. Steiner, Landscape ecological urbanism: Origins and trajectories, Landsc. Urban Plan. 100 (2011) 333–337.
[199] K.L. Strandberg, Monitoring, datafication and consent: Legal approaches to privacy in the big data context, in: J. Lane, V. Stodden, S. Bender, H. Nissenbaum (Eds.), Privacy, Big Data and the Public Good, Cambridge University Press, Cambridge, UK, 2014, pp. 5–43.
[200] J. Stübinger, L. Schneider, Understanding smart city—a data-driven literature review, Sustainability 12 (2020) 8460, doi:10.3390/su12208460.
[201] Y. Sun, Y. Du, Big data and sustainable cities: applications of new and emerging forms of geospatial data in urban studies, Open Geospat. Data Softw. Stand. 2 (2017) 24, doi:10.1186/s40965-017-0037-0.
[202] H. Suzuki, et al., Eco2 Cities Ecological Cities as Economic Cities, The World Bank, 2010.
[203] P.V. Thakuriah, N. Tilahun, M. Zellner, Seeing cities through big data research, Methods and Applications in Urban Informatics, Springer International Publishing, 2017.
[204] M. Thornbush, O. Golubchikov, Sustainable Urbanism in Digital Transitions: From Low Carbon To Smart Sustainable Cities, Springer, Berlin, 2019.
[205] N. Thrift, The 'sentient' city and what it may portend, Big Data Soc. 1 (2014) 2053951714532241.
[206] A.M. Toli, N. Murtagh, The concept of sustainability in smart city definitions, Front. Built Environ. 6 (2020) 77, doi:10.3389/fbuil.2020.00077.
[207] Z. Tomor, A. Meijer, A. Michels, S. Geertman, Smart governance for sustainable cities: findings from a systematic literature review, J. Urban Technol. 26 (4) (2019) 3–27.
[208] G. Trencher, Towards the smart city 2.0: Empirical evidence of using smartness as a tool for tackling social challenges, Technol. Forecast. Soc. Change 142 (2019) 117–128.
[209] E.P. Trindade, M.P.F. Hinnig, E. Moreira da Costa, J.S. Marques, R.C. Bastos, T. Yigitcanlar, Sustainable development of smart cities: a systematic review of the literature, J. Open Innov. Technol. Mark. Complex. 3 (3) (2017) 11, doi:10.1186/s40852-017-0063-2.
[210] UNEPThe Weight of Cities–Resource Requirements of Future Urbanization, International Resource Panel Secretariat, Paris, 2018.
[211] UN HabitatIssue Paper on Urban and Spatial Planning and Design, United Nations Human Settlements Programme 2015, Nairobi, Kenya, 2015.
[212] United Nations (2015a). Transforming Our World: the 2030 Agenda for Sustainable Development. New York. Available at:. https://sustainabledevelopment.un.org/post2015/transformingourworld
[213] United Nations (2015b) Habitat III Issue Papers, 21—Smart cities (V2.0), New York. Available at: https://unhabitat.org/issue-papers-and-policy-units [Accessed 2 May 2017]
[214] United Nations (2018). The Sustainable Development Goals Report. Available online at: https://www.un.org/development/desa/publications/the-sustainable-development-goals-report-2018.html
[215] H. Verrest, K. Pfeffer, Elaborating the urbanism in smart urbanism: distilling relevant dimensions for a comprehensive analysis of Smart City approaches, Information, Commun. Soc. 22 (9) (2019) 1328–1342, doi:10.1080/1369118X.2018.1424921.
[216] E. Van Bueren, H. van Bohemen, L. Itard, H. Visscher, Sustainable Urban Environments: An ecosystem approach, Springer International Publishing, 2011.
[217] J. Viitanen, R. Kingston, Smart cities and green growth: outsourcing democratic and environmental resilience to the global technology sector, Environ. Plan. A 46 (2014) 803–819, doi:10.1068/a46242.
[218] X.X. Wang, L.H. Xu, K.X. Chen, Data-driven short-term forecasting for urban road network traffic based on data processing and LSTM-RNN, Arab. J. Sci. Eng. 44 (4) (2019) 3043–3060.
[219] C.W.R. Webster, C. Leleux, Smart governance: opportunities for technologically mediated citizen co-production, Inf. Polity (2018) 1–16.
[220] J. Webster, R.T. Watson, Analyzing the past to prepare for the future: writing a literature review, MIS Q. 26 (2) (2002) 13–23.
[221] S.M. Wheeler, T. Beatley (Eds.), The Sustainable Urban Development Reader, Routledge, London, New York, 2010.
[222] K. Williams, Sustainable cities: research and practice challenges, Int J Urban Sust Dev 1 (1) (2010) 128–132.
[223] K. Williams, E. Burton, M. Jenks (Eds.), Achieving Sustainable Urban Form, E & FN Spon, London, 2000.
[224] T.-C. Wong, B. Yuen, Understanding the origins and evolution of eco-city development: an introduction, in: T.-C. Wong, B. Yuen (Eds.), Eco-City Planning: Policies, Practice and Design, Springer, Dordrecht; London, 2011, pp. 1–16.
[225] T. Xu, G. Han, X. Qi, J. Du, C. Lin, L. Shu, A hybrid machine learning model for demand prediction of edge-computing-based bike-sharing system using Internet of Things, IEEE Internet Things J. 7 (8) (2020) 7345–7356, doi:10.1109/JIOT.2020.2983089.
[226] T. Yigitcanlar, F. Cugurullo, The sustainability of artificial intelligence: an Urbanistic viewpoint from the lens of smart and sustainable cities, Sustainability 12 (2020) 8548.
[227] T. Yigitcanlar, D. Dizdaroglu, Ecological approaches in planning for sustainable cities: a review of the literature, Glob. J. Environ. Sci. Manag. 1 (2) (2014) 159–188.
[228] T. Yigitcanlar, Kamruzzaman, M. Md Foth, J. Sabatini-Marques, E. da Costa, G. Ioppolo, Can cities become smart without being sustainable? A systematic review of the literature, Sustain. Cities Soc. 45 (2019) 348–365.
[229] Y. Zheng, Urban computing: enabling urban intelligence with big data, Front. Comput. Sci. 11 (2017) 1–3, doi:10.1007/s11704-016-6907-2.
[230] Y. Zheng, L. Capra, O. Wolfson, H. Yang, Urban computing: concepts, methodologies, and applications, ACM Trans. Intell. Syst. Technol. 5 (3) (2014) 222–235.
[231] Y. Zheng, W. Yi X, M. Li, Y. Li R, Q. Shan Z, E. Chang, R. Li T, Forecasting fine–grained air quality based on big data, in: Proceeding of the 21st SIGKDD Conference on Knowledge Discovery and Data Mining, (KDD 2015), 2015, pp. 2267–2276.
[232] B. Zhang J, Y. Zheng, K. Qi D, Deep spatio-temporal residual networks for citywide crowd flows prediction, in: Proceedings of the 31st AAAI Conference on Artificial Intelligence, 2016.
[233] S. Zygiaris, Smart city reference model: assisting planners to conceptualize the building of smart city innovation ecosystems, J. Knowl. Econ. 4 (2013) 217–231, doi:10.1007/s13132-012-0089-4.