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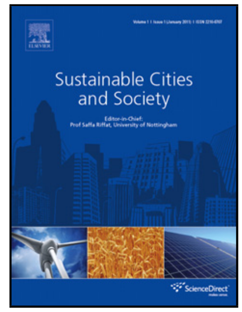

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Smart Sustainable Cities of the Future:
An Extensive Interdisciplinary Literature Review

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Highlights

- The overview of existing work on smart sustainable cities is comprehensive, thorough, and original.
- Several critical issues remain unsettled, less explored, and theoretically underdeveloped for applied purposes
- New opportunities exist and can be realized in the ambit of smart sustainable city development
- There is a need for the development of a theoretically and practically novel model of smart sustainable urban form
- The proposed approach is believed to be the first of its kind into addressing the challenge of urban sustainability

Abstract

In recent years, the concept of smart sustainable cities has come to the fore. And it is rapidly gaining momentum and worldwide attention as a promising response to the challenge of urban sustainability. This pertains particularly to ecologically and technologically advanced nations. This paper provides a comprehensive overview of the field of smart (and) sustainable cities in terms of its underlying foundations and assumptions, state–of–the art research and development, research opportunities and horizons, emerging scientific and technological trends, and future planning practices. As to the design strategy, the paper reviews existing sustainable city models and smart city approaches. Their strengths and weaknesses are discussed with particular emphasis being placed on the extent to which the former contributes to the goals of sustainable development and whether the latter incorporates these goals. To identify the related challenges, those models and approaches are evaluated and compared against each other in line with the notion of sustainability. The gaps in the research within the field of smart sustainable cities are identified in accordance with and beyond the research being proposed. As a result, an integrated approach is proposed based on an applied theoretical perspective to align the existing problems and solutions identification for future practices in the area of smart sustainable urban planning and development. As to the findings, the paper shows that critical issues remain unsettled, less explored, largely ignored, and theoretically underdeveloped for applied purposes concerning existing models of sustainable urban form as to their contribution to sustainability, among other things. It also reveals that numerous research opportunities are available and can be realized in the realm of smart sustainable cities. Our perspective on the topic in this regard is to develop a theoretically and practically convincing model of smart sustainable city or a framework for strategic smart sustainable urban development. This model or framework aims to address the key limitations, uncertainties, paradoxes, and fallacies pertaining to existing models of sustainable urban form—with support of ICT of the new wave of computing and the underlying big data and context–aware computing technologies and their advanced applications. We conclude that the applied theoretical inquiry into smart sustainable cities of the future is deemed of high pertinence and importance—given that the research in the field is still in its early stages, and that the subject matter draws upon contemporary and influential theories with practical applications. The comprehensive overview of and critique on existing work on smart (and) sustainable cities provide a valuable and seminal reference for researchers and practitioners in related research communities and the necessary material to inform these communities of the latest developments in the area of smart sustainable urban planning and development. In addition, the proposed integrated approach is believed to be the first of its kind and has not been, to the best of one's knowledge, produced elsewhere.

Keywords Smart cities, sustainable cities, smart sustainable cities, sustainable urban forms, urban sustainability, sustainable development goals, ICT, computing, planning, big data analytics, context–aware computing

1. Introduction

It has been estimated by the United Nations that by 2050 66% of the world's population will live in cities (United Nations 2015). This implies significant challenges pertaining to environmental and social sustainability (OECD 2012). In addition, the form of contemporary cities has been viewed as a source of environmental and social problems. Cities consume about 70% of the world's resources and hence are major consumers of energy resources and significant contributors to greenhouse gas (GHG) emissions due to the density of urban population and the intensity of related economic and social activities, in addition to the inefficiency of the built environment. Therefore, contemporary debates in urban and academic circles continue to focus on the role of sustainability in urban planning and development in terms of responding to the substantial challenges arising from the rapidly evolving urbanization as well as the unsustainability of existing urban forms. The way forward for cities to better cope with the changing and restructuring conditions is to adopt the long–term approaches that focus on sustainability (see Bulkeley and Betsill 2005). This is to mitigate the adverse effects that these cities might encounter as a result of stretching beyond the capacities and designs of urban systems accompanying urban growth (e.g. Antrop 2004). In contemporary cities, urban systems—processes which operate and organize urban life in the form of built form, infrastructure, ecosystem services, human services, and administration—are under increasing pressure due to the enormous challenge of sustainability, coupled with the greatest wave of urbanization in history. The existing built environment is already associated with numerous environmental, social, and economic impacts, including unsustainable energy use and concomitant GHG emissions, increased air and water pollution, environmental degradation, land use haphazard, inappropriate urban design and related social deprivation and community disruption, ineffective mobility and accessibility, increased transport needs and traffic congestion, public safety and health decrease, but to name a few. Adding to this are the outdated (non–automated, non–digital) infrastructures within cities, which pose technical and physical problems (e.g. Colldahl, Frey and Kelemen 2013). In particular, the form of contemporary cities affects people, natural resources, habitat, and climate (e.g. Jabareen 2006). These effects are set to worsen with increased urbanization due to the issues it engenders in relation to sustainability. Urban growth raises a variety of problems that tend to jeopardize the environmental, economic, and social sustainability of cities (e.g. Neirotti et al. 2014). In more detail, the rapid urbanization of the world, albeit an emblem of social evolution, gives rise to numerous challenges associated with intensive energy consumption, endemic congestion, saturated transport networks, air and water pollution, toxic waste disposal, resource depletion, social inequality and vulnerability, public health decrease, and so on. In a nutshell, as a dynamic clustering of people, buildings, infrastructures, and resources (Bibri 2013), urbanization puts an enormous strain on urban systems, thereby stressing urban life in terms of the underlying operating and organizing processes, functions, and services.

The above intractable problems require evidently an unprecedented paradigm change to disentangle and overcome—i.e. newfangled ways of urban thinking grounded in a holistic approach and long–term perspective with respect to the conception, planning, and development of the built, infrastructural, operational, and functional forms of cities. Towards this end, there is an urgent need first to develop, apply, and mainstream innovative solutions and sophisticated methods in the area of urban planning and development. This urgency is also to overcome the challenges of urbanization (European Commission 2014; United Nations 2016). Therefore, ICT has recently become part of mainstream debate on urban sustainability as well as urbanization due to the ubiquity presence of urban computing and the massive use of urban ICT in urban systems and domains. Indeed, data sensing and information processing are being fast embedded into the very fabric of contemporary cities while wireless networks are proliferating on a hard–to–imagine scale (Batty et al. 2012; Bibri and Krogstie 2016b). This is underpinned by the recognition that the planning of cities as dynamic and evolving systems towards sustainability in terms of how they function and can be managed and developed necessitates smart, data–centric technologies. Against the backdrop of the unprecedented rate of urbanization, alternative ways of thinking about and conceiving of cities are materializing (see Batty 2013) as to how they can transition to the needed sustainable development in light of advanced ICT (see Bibri and Krogstie 2016a, b). Besides, the way cities can intelligently be planned and developed has been of fundamental importance for strategic sustainable development to achieve the long–term goals of sustainability. To put it differently, ICT in its various forms (infrastructures, applications, data analytics capabilities, and services) is increasingly seen to provide unsurpassed ways to address a range of complex environmental challenges and rising socio–economic concerns facing contemporary cities. In fact, ICT is already enabling cities in many parts of the world to remain sustainable and thus livable in the face of staggering urbanization, growing social mobility, and ongoing transformation. An increasing urgency to find and adopt smart solutions is driven by urban growth in terms of seeking out ways to address the associated challenges and ensuing effects (see Nam and Pardo 2011). Townsend (2013) portrays ICT development and urban growth as a form of symbiosis. This entails an interaction that is of advantage to or a mutually beneficial relationship between ICT and urban growth. By the same token, the planning of cities as complex systems towards sustainability requires innovative ideas and sophisticated methods and techniques (e.g. Colldahl, Frey and Kelemen 2013; Kramers et al. 2013, 2014; Rotmans, van Asselt and Vellinga 2000; Shahrokni et al. 2015). This entails the application of complexity sciences upon which ICT is founded (Bibri and Krogstie 2016a). Indeed, a large number of advanced technologies are being developed and applied in response to the urgent need for dealing with the complexity of the knowledge necessary for enhancing, harnessing, and integrating urban systems and facilitating collaboration and coordination among urban domains in the realm of smart sustainable urban planning and development (Bibri and Krogstie 2016b). ICT plays a key role in smart sustainable urban planning (Bifulco et al. 2016). ICT development and sustainability awareness have resulted in an opportunity to rethink the way we plan cities (Höjer and Wangel 2015) and to develop new ways of understanding and addressing urban challenges and problems (Batty et al. 2012).

When discussing sustainability and ICT and thus sustainable practices and smart solutions for cities, reference is made to the two concepts of sustainable cities and smart cities. Scholars from different disciplines and practitioners from different professional fields have, over the past two decades or so, sought a variety of sustainable city models as well as smart city approaches that can contribute to sustainability and its improvement. Compact city and eco–city (e.g. Jabareen 2006; Jenks, Burton and Williams 1996a, b; Joss 2010, 2011; Joss, Cowley and Tomozeiu 2013; Neuman 2005; Register 2002) are the most prevalent models of sustainable city (e.g. Hofstad 2012; Jabareen 2006; Kärrholm 2011; Rapoport and Verney 2011). However, the challenge continues to motivate and induce academics and planners as well as policymakers and decision–makers to work collaboratively to put forward new approaches into redesigning and rearranging urban areas across many spatial scales to achieve the required level of sustainability, especially in relation to integrating its environmental, economic, social, and cultural dimensions. The ultimate goal revolves around developing more convincing and robust sustainable city models. This has been one of the most significant intellectual challenges and research endeavors for more than two decades. This implies that it has been difficult to, in addition to translating sustainability into the built form of cities, evaluate whether and the extent to which the so–called sustainable urban forms contribute to the goals of sustainable development (see, e.g., Jabareen 2006; Kärrholm 2011). Indeed, existing models of sustainable urban form still pose several conundrums and raise numerous issues—when it comes to their development and implementation as to their contribution to the fundamental goals of sustainable development. This pertains to limitations, uncertainties, paradoxes, and fallacies. One implication of this is that more innovative solutions and more sophisticated approaches are needed to overcome these challenges and issues, and important and relevant questions in this regard involve how these forms should be monitored, understood, analyzed, and planned to improve sustainability. The underlying argument is that urban systems have been in themselves complex in terms of their operation, management, assessment, and planning in line with the vision of sustainability. Here comes the role of ICT into play given its foundation on the application of complexity sciences to urban systems and problems (Batty et al. 2012; Bibri and Krogstie 2016b). With that in mind, while the development of compact city and eco–city has been, for about two decades, the preferred response to the challenge of sustainability (see, e.g., Roseland 1997; Jenks, Burton and Williams 1996a; Hofstad 2012; Jabareen 2006; Kärrholm 2011; Joss 2011; Rapoport and Vernay 2011), the development of smart city with its various faces has come to the fore in recent years as a promising response to the same challenge (e.g. Al Nuaimi et al. 2015; Batty et al. 2012; Neirotti et al. 2014)—by developing smart solutions for sustainability, optimizing efficiency in urban systems, and enhancing the quality of life of citizens. This can occur through connecting urban systems and assessing their sustainability performance; eliminating redundancy in urban operations and services; and pinpointing which urban domains, facilities, and networks to couple, coordinate, and integrate. The smart solutions have proven track records as to enhancing many processes and practices in large cities. Indeed, it is in such cities that the key to a better world—which is held by ICT—will be most evidently demonstrated (Batty et al. 2012). The prosperity of many cities and their ability to address their complex challenges through advanced ICT is one of the key reasons why much attention has been given to smart city as an urban development strategy. Cities can evolve in ways that intelligently address the environmental concerns and meet the social needs of their citizens (Murray, Minevich and Abdoullaev 2011), as they are the incubators, generators, and transmitters of innovative ideas and smart solutions for solving many challenges. However, like sustainable city models, existing smart city approaches present significant challenges and raise many issues—when it comes to their development and implementation as to their incorporation of the fundamental goals of sustainable development. This pertains to deficiencies, inadequacies, and misunderstandings. Regardless, of most relevance to highlight is that there is a lack of connection between smart cities and sustainable cities, despite the great potential and proven role of ICT in supporting cities in their transition towards sustainability, especially in relation to the operation, management, and planning of urban systems (e.g. Batty et al. 2012; Bibri and Krogstie 2016a, b; Kramers et al. 2014). It is important to understand how the concepts of smart cities and sustainable cities relate to each other (Bifulco et al. 2016).

In light of the above, recent research endeavors have started to focus on how to incorporate sustainability in smart city approaches and to smarten up sustainable city models (e.g. Al Nuami et al. 2015; Batty et al. 2012; Bibri and Krogstie 2017; Kramers et al. 2014; Neirotti et al. 2014; Shahrokni et al. 2015). One optimal way of doing so is by integrating the two perspectives as urban development strategies in an attempt to achieve the required level of sustainability with respect to urban operations, functions, services, and designs. This holistic approach has been seen to hold great potential to address the challenge of, or provide solutions for moving towards, urban sustainability (e.g. Batagan 2011; Höjer and Wangel 2015; Kramers et al. 2014; Murray, Minevich and Abdoullaev 2011). Thereby, the concept of smart sustainable cities has come to the fore, and is rapidly gaining momentum as a holistic approach to urban development and as an academic pursuit, not least in ecologically and technologically advanced societies (Bibri and Krogstie 2016a). That is to say, it is increasingly becoming an important concept not only in urban research and planning, but also in city policy and politics, thus generating worldwide attention as a powerful framework for strategic sustainable urban development (see, e.g., Al–Nasrawi, Adams and El–Zaart 2015; ITU 2014; Höjer and Wangel 2015). It is worth noting that the emergence of this new techno–urban phenomenon has been particularly fueled by what is labeled 'ICT of the new wave of computing'—i.e. a combination of various forms of pervasive computing, the most prevalent of which are Ubiquitous Computing (UbiComp), Ambient Intelligence (AmI), the Internet of Things (IoT), and Sentient Computing (SenComp) (Bibri and Krogstie 2016a). Besides, we live in a world where computing and ICT have become deeply embedded into the very fabric of contemporary cities, i.e. urban operations, functions, services, and designs are pervaded with computation and intelligence. In view of that, for existing sustainable city models, in particular, to prosper, they need to embrace what ICT has to offer as innovative solutions and sophisticated methods for sustainability in order to smarten up as to making urban living more sustainable over the long run—in an increasingly computerized urban society. This is predicated on the assumption that advanced ICT offers tremendous potential for monitoring, understanding, probing, assessing, and planning cities, which can be leveraged in the improvement of urban sustainability.

The purpose of this paper is to provide a comprehensive overview of the field of smart (and) sustainable cities in terms of its underlying foundations and assumptions, state–of–the art research and development, opportunities and horizons, emerging scientific and technological trends, and future planning practices. This extensive literature review endeavors to present a detailed analysis, critical evaluation, and interdisciplinary synthesis of the available qualitative research covering the topic of smart and sustainable cities in line with the concepts that we have set ourselves for the research, with a particular emphasis on cross–disciplinary issues. The questions this literature review addresses are the following:

What are the key scholarly sources that are relevant, authoritative, and topical?
What are the key theories, concepts, and academic discourses?
What are the intellectual origins and definitions of the topic?
What are the main questions and problems that have been addressed to date?
What are the major issues, debates, and challenges relating to the topic?
What are the available and worth exploring research opportunities and horizons in the field?
What are the emerging scientific and technological trends and future planning practices in the field?

The approaches to these questions are primarily intended to enhance our understanding and knowledge of the flourishing field of smart sustainable cities. The motivation for this paper—and hence the rationale behind our pursuit of research within the area of smart sustainable urban development—is threefold: (1) the interdisciplinary academic field of smart sustainable cities is evolving into a scholarly and realist techno–urban enterprise; (2) it is gaining momentum as a societal pursuit in ecologically and technologically advanced nations; and (3) it has become of high importance and relevance to capture further and invigorate the application demand for the smart solutions for urban sustainability and its advancement that emerging and future urban ICT can offer. The main added value of this paper lies in highlighting the need for ICT development and innovation to be linked with sustainable development, and thus related future investment to be justified by environmental concerns and socio–economic needs, rather than technical advancement and industrial competitiveness. Other added values involve its thoroughness (i.e. including numerous sources), topicality (i.e. addressing subjects of immediate relevance and importance due to their relation to current urban phenomena), and original contribution (i.e. new terminology for understanding and discussing the field and novel deep insights about the field as a result of analyzing and synthesizing the various available works).

The remainder of this paper proceeds as follows. Section 2 outlines the search, selection, and organization approaches into the literature review, as well as its purposes in the context of our study. In Section 3, we introduce, describe, and discuss the main conceptual, theoretical, and discursive constructs that make up our study. In Section 4, we present a survey of related research work and critically discuss, analyze, and evaluate key issues, debates, and challenges. Section 5 highlights and encapsulates research opportunities and horizons for smart sustainable cities. In Section 6, we shed light on future urban planning practices and emerging scientific and technological trends. We present our concluding remarks, contributions, and final thoughts in Section 7.

2. Literature Review Search, Selection, and Organization Approaches and Purposes

The field of smart sustainable cities is profoundly interdisciplinary. Hence, this literature review involves the exploration of an extensive and broad array of material (including journal articles, books, reports, conference proceedings, dissertations, theses, and policy documents) at the intersection of various disciplinary areas of relevance to the intended research topic, and focuses on the existing and established theory and qualitative research. It is carried out based on an integration of technical and social perspectives (Levy and Ellis 2006; Webster and Watson 2002). Accordingly, we defined a review protocol and developed a review method as a means to indicate the questions to be addressed, search strategies to retrieve articles and other documents from various sources, inclusion and exclusion criteria for identifying relevant articles and other documents, and abstract review protocols.

2.1. Search Strategy and Scholarly Sources

To find out what has already been written on the topic of smart sustainable cities, an extensive search of the literature was performed. The objective of our search strategy was to identify the relevant studies into smart (and) sustainable cities. Of importance to underscore here is that the preliminary selection of available material was done in line with the research being proposed or the problem being investigated, using a variety of academic sources that are relevant, current, and authoritative. That is, the search for the intended published work was directed with our main research question (thesis) in mind: How to advance the contribution of existing sustainable urban forms to the goals of sustainable development with support of emerging and future ICT—enabled by the new wave of computing—under what is labelled 'smart sustainable cities' of the future? This entails an effective integration of the typologies and design concepts of the prevalent models of sustainable city with the ICT solutions pertaining to the most advanced models of smart city, with the aim of improving urban sustainability. However, we used standard search strategies involving querying a variety of relevant academic or scholarly sources, namely electronic (cross–disciplinary) databases as well as Google scholars. We searched independently a number of international journals and conference proceedings. The main contributions came from quality journal articles based on Scott's (1990) four criteria for assessing quality: authenticity, credibility, representation, and meaning. The examined period as to sustainable cities was (mainly) from 2005 to 2016, and as to smart cities was from 2005 to 2016. Regarding smart sustainable cities. it was only around the mid 2010s when the concept emerged, so the examined period was from 2015 and onward. The searched keywords included 'smart cities', 'smart cities AND future', 'smart cities AND sustainability', 'sustainable cities', 'sustainable urban forms', 'compact city', eco–city', 'ambient city', 'sentient city', 'ubiquitous city', 'the IoT AND smart city', 'smart sustainable cities', 'big data analytics AND smart cities', 'big data analytics AND sustainability', 'context–aware computing and smart cities', 'context–aware computing AND sustainability', as well as derivatives of these terms. We used these keywords to search against such categories as the articles' keywords, title, and abstract to produce some initial insights into the field on focus. To note, due to the shortcomings associated with relying on the keyword approach (levy and Ellis 2006), we additionally used backward literature search (backward authors, backward references, and previously used keywords) and forward literature search (forward authors and forward references) (Webster and Watson 2002). For concepts, theories, and academic discourses, the searched keywords included 'sustainability', 'sustainable development', ‘sustainability science’, ‘urban sustainability’, ‘sustainable urban development’, ‘urban planning, ‘urban design’, ‘urban ICT’, ‘urban computing’, ‘smart cities’, ‘sustainable cities’, and ‘smart sustainable cities’.

2.2. Inclusion and Exclusion Criteria

The key questions for which previous and current research or results from qualitative analyses on smart (and) sustainable cities were sought were employed to further select the relevant documents, in particular journal articles, for reading. This selection was initially bounded with the aforementioned research question. This is underpinned by the recognition that once we have our research question we will be able to refine and narrow down the scope of our reading, although there may seem to be hundreds of sources of information that appear pertinent. With that in mind, to be considered an article that provided information or evidence on the questions being addressed, the article had to cover one of the conceptual subjects or thematic categories intended to be elaborated on and discussed or analyzed and evaluated. Our focus was on articles that provided definitive primary information from a systematic review. While certain methodological guidelines were deemed essential to ensure the validity of the review, it was of equal importance to allow flexibility in the application of the proposed approach to capture the essence of research within the rather flourishing interdisciplinary field of smart sustainable cities. The whole idea was to ensure that we ‘accumulate a relatively complete census of relevant literature’ (Webster and Watson 2002, p. 16). With the above in mind, to ensure an effective outcome, we excluded articles that did not meet specific criteria in terms of relevance to the research questions being addressed. We therefore assessed each of the published articles accordingly. Specifically, we scored them for the inclusion of issues and themes relating to these questions, keeping in in mind the aim of relating the literature to and explaining our main research question. As to abstract review, each citation and the abstract were reviewed to assess relevance to the interdisciplinary review and to ensure reliable application of the inclusion and exclusion criteria. And inclusionary discrepancies were resolved by re–review. The process enabled us to refine and narrow down the scope of our reading. The exclusion involved specific criteria in terms of the quality of the research on the topic, including information source adequately searched and applicable, inclusion/exclusion criteria comprehensible and applicable, and the approaches into combining results applicable. However, we attempted at the outset of the literature process to read quite broadly on the topic to enrich our understanding of the field. Indeed, this is useful for establishing the perspective that our research will take in terms of how it will extend or enhance the existing knowledge in the field, as well as for refining our topic in terms of working out where there are gaps in the existing knowledge, which has provided us with a niche for our study. In a nutshell, the literature review needs to explain and relate to the main research question. In addition, we discovered during the search that some advanced aspects of emerging and future ICT in the realm of smarter cities in relation to sustainability were part of (ongoing) studies not yet reported in the literature.

2.3. A Combination of Organizational Approaches

This literature review is organized using a combination of structural approaches, namely thematic, inverted pyramid, and the benchmark studies. This means that the research is divided into sections representing both the conceptual subjects as well as the thematic categories for the topic on focus. The discussion of the related literature is organized accordingly while, when appropriate, starting from a broad perspective and then dealing with more and more specific perspectives from studies associated with the research problem. In doing so, the discussion focuses on the major writings considered as significant in the field of smart (and) sustainable cities.

2.4. Specific Purposes

The literature review is typically performed to serve many purposes. This tends to differ slightly depending on the academic nature and level of the study being carried out. Here the literature review was done for our study to serve specific purposes, which include the following:

- To determine what has been done in terms of the research being proposed.
- To provide an overview of key concepts, theories, and discourses
- To study the definitions adopted in the research, with the purpose of espousing them for our study.
- To broaden our horizons and gain insight into the problem at hand.

- To evaluate and synthesize the existing information in line with the concepts set for our study.
- To discuss and analyze the relevant information written about the topic.
- To provide a solid background and theoretical foundation for our study.
- To familiarize ourselves with the latest developments in the field.
- To highlight the strengths, weaknesses, omissions, and conflicting evidence of the existing knowledge, thereby providing a critique of the research.
- To discover major relationships between different research results by comparing various studies.
- To identify the gaps in the existing research that our study is endeavoring to address, positioning our work in the context of previous research and creating a research space for it.
- To situate our work within prominent research trends to establish its significance.
- To produce a rationale and establish the need for our study and thus justify its originality.

3. Conceptual, Theoretical, and Discursive Foundations and Assumptions

3.1. Sustainability and Sustainable Development

The notion of sustainability was born from the realization that the predominant paradigm of social, economic, and urban development was oblivious to the risks of and triggering environmental crises as well as to the implications of and worsening social decays, causing ecological and social deprivation and imperiling future life. Sustainability epitomizes a holistic, long–term perspective based on the premise of consciously and incessantly going with the grain of nature and providing the conditions for deploying the frameworks necessary for its operationalization and its translation into practices in a more intelligent way in order to reach a sustainable society. Generating immediate worldwide attention upon the widespread dissemination of the concept of sustainable development in the late 1980s, followed by an unprecedented prevalence and wide adoption of related strategies, sustainability embodies a unique productive and constitutive force as a large–scale societal discourse. As a societal thinking paradigm, sustainability is espoused to guide and configure societal development in its prominent spheres, including science and innovation, technology, economy, urban planning, policy, politics, and institutionalization. The underlying premise is that it is grounded in an all–embracing understanding of the challenges and problems facing society, which is necessary for making all–inclusive decisions and taking well–informed actions for its long–term benefit.

There is no canonical or definite definition of sustainability. It is a difficult concept to delineate given its contested, philosophical, normative, and multifaceted nature, in addition to the complexity of the socio–ecological system to which it is applied (e.g. Bibri 2015b; Huckle 1996; McManus 1996; Molnar, Morgan and Bell 2001). In general terms, sustainability can be conceived of as a state in which society doesn't undermine the natural and social systems, i.e. where the natural system is not subject to resource depletion and intensive consumption, hazardous substances, and concomitant environmental risks, and, as of equal importance, where the social system doesn't render people subject to conditions that inhibit their ability to satisfy their needs and aspirations. Undermining natural and social systems can occur through pollution, environmental degradation/ecological deprivation, health decrease, social instability, social injustice, and social hazard.

Sustainable development is a process of change and strategic approach to achieve the long–term goals of sustainability: a balanced socio–ecological system (Bibri 2013; Bibri 2015b). It has emerged as a global response to the environmental crises triggered by anthropogenic activities and the escalating social inequalities and injustices. The concept of sustainable development was introduced by the Bruntland Report in 1987, in which it denotes 'development that meets the needs [and aspirations] of the present without compromising the ability of future generations to meet their own needs.' (WCED 1987, p. 43) However, this classic definition has been misconstrued and misused and generated several critiques. As a result, the concept has become widely multifarious, highly contested, and oftentimes contradictory and oxymoronic (e.g. Hopwoodil, Mellor and O'Brien 2005; Jacobs 1999; Jöst 2002; Munda 1997; Murcott 1997; Redclift 1987, 2005). The lack or absence of a more universal definition of sustainable development has given rise to multiple interpretations and philosophical underpinnings, which has consequently triggered or led to an explosion of environmental, social, and economic indicators. However, as one among many other alternative definitions in the literature, sustainable development is described by Bibri (2015b, p. 53) as 'the planned and strategic development processes of working towards a balance of economic, environmental, and social values and goals, i.e. a balance of the need for economic development and prosperity with environmental protection and integrity and social equity and justice. The premise is to conciliate the continuity of these—conflicting, competing, and sometimes contradictory—forces' or realms.

3.2. Sustainability Science

Just like the definition of sustainability, consensual definition of sustainability science is difficult to pin down. Broadly, sustainability science entails advancing knowledge on how the natural and human systems interact in terms of the underlying (changing) dynamics, with the purpose of designing, developing, implementing, evaluating, and perennially enhancing engineered systems as practical solutions and interventions that support the idea of the socio–ecological system in balance, as well as nurturing and sustaining linkages between scientific research and technological innovation and policy and public administration processes in relevance to sustainability. The concept is defined as 'the cultivation, integration, and application of knowledge about Earth systems gained especially from the holistic and historical sciences…coordinated with knowledge about human interrelationships gained from the social sciences and humanities, in order to evaluate, mitigate, and minimize the consequences…of human impacts on planetary systems and on societies across the globe and into the future.' (Kieffer et al. 2003, p. 432) As a flourishing academic discipline, sustainability science has emerged in the early 2000s (e.g. Kates et al. 2001*;* Clark and Dickson 2003; Clark 2007). As an interdisciplinary field, it brings together disciplines across the natural sciences, social sciences, and applied and engineering sciences. As a research field, it probes the complex mechanisms and patterns involved in the profound interactions between social, environmental, and engineered systems to understand their behavioral patterns and changing dynamics and to contribute to developing (rather upstream) solutions for tackling complex challenges associated with systematic degradation of these systems and with concomitant perils to human well–being. That is, challenges that imperil the integrity of the planet's life support systems and compromise the future of human life. This research field seeks to give the 'broad–based and crossover approach' of sustainability a solid scientific foundation. It also provides a critical and analytical framework for sustainability (Komiyama and Takeuchi 2006), and 'must encompass different magnitudes of scales (of time, space, and function), multiple balances (dynamics), multiple actors (interests), and multiple failures (systemic faults)' (Reitan 2005, p. 77). To add, sustainability science can be thought of or viewed as 'neither "basic" nor "applied" research but as a field defined by the problems it addresses rather than by the disciplines it employs; it serves the need for advancing both knowledge and action by creating a dynamic bridge between the two' (Clark 2007, p. 1737).

From a broader perspective of sustainability science, some views highlight the need to probe the root causes of the fundamental unsustainability of the predominant paradigms of technological, economic, and societal development. In this line of thinking, Bibri (2015b) analyzes the implications of ICT of the new wave of computing as technological developments for environmental and societal sustainability. Brown (2012) contends that sustainability science must involve the role of technology in as well aggravating the unsustainability of social practices as in tackling the problems these practices generate, and also the study of the societal structures as to material consumption. The attempt to grasp the integrated whole of the socio–ecological system in terms of the complex social and multidimensional environmental aspects and problems necessitates globally integrated political consensus and collaboration between institutional, social, economic, scientific, and technological disciplines, as well as the active engagement of citizens, communities, organizations, and institutions. One key mission of sustainability science is to aid in coordinating cross–disciplinary integration necessary as a critical step towards a global joint effort and concerted action. In addition, the way in which sustainability science as a scholarly community can best contribute to the understanding and implementation of the goals of sustainable development should be based on an in–depth critical analysis and evaluation through scenario analysis, scientific research, technological innovation, stakeholder relationships, participatory decision–making, and policy recommendations and impacts. In a nutshell, to achieve these goals requires taking an all–inclusive approach by mobilizing diverse actors, factors, and resources.

3.3. Urban Sustainability and Sustainable Urban Development

The concepts of sustainability and sustainable development have been applied to urban planning and design since the early 1990s (e.g. Wheeler and Beatley 2010), thereby the emergence of the notions of urban sustainability and sustainable urban development. Urban sustainability denotes a desired state in which the urban society strives for achieving a balance between environmental protection and integration, economic development and regeneration, and social equity and justice within cities as long–term goals through the strategic process of sustainable urban development as a desired trajectory. Thereby, it seeks to create healthy, livable, and prosperous human environments with minimal demand on resources (energy, material, etc.) and minimal impact on the environment (toxic waste, air and water pollution, hazardous chemicals, etc.), to draw on

Bibri (2013). This overall goal entails fostering linkages between scientific and social research, technological innovation, institutionalized and organizational practices, and policy design and planning in relevance to urban sustainability. Urban sustainability tends to be cast in terms of four dimensions: the form, the environment, the economy, and equity, which should all—given their interdependence, synergy, and equal importance—be enhanced over the long run in a sustainable urban society. Accordingly, contemporary cities should retain a balance between physical, environmental, economic, and social concerns and goals. To achieve this long–term goal requires an urban development strategy that facilitates and contributes to the design, development, implementation, evaluation, and improvement of urban systems and other practical interventions within various urban domains that promote urban sustainability in terms of replenishing resources, lowering energy use, lessening pollution and waste levels, as well as improving social justice, stability, and safety. This is what sustainable urban development is about. This concept signifies, in other words, the development (and/or redevelopment) of cities in ways that provide livable and healthy human environments with enhanced quality of life and well–being in conjunction with decreased demand on resources and lessened environmental impacts, to iterate, thereby steering clear of leaving a burden on the future generations due to potential environmental degradation or ecological deprivation. Richardson (1989, p.14) defines sustainable urban development as 'a process of change in the built environment which foster economic development while conserving resources and promoting the health of the individual, the community, and the ecosystem.' In a nutshell, sustainable urban development is characterized as achieving a balance between the development of and equity in the urban areas and the protection of the urban environment. However, conflicts among the goals of sustainable urban development to achieve the long–term goals of urban sustainability are challenging to deal with and daunting to overcome. This has indeed been, and continues to be, one of the toughest challenges facing urban planners and scholars as to decision–making and planning in the realm of sustainable cities (Bibri and Krogstie 2017), not to mention smart cities due to the multidimensional risks they pose to environmental sustainability (Bibri and Krogstie 2016a). Despite sustainable urban development seeking to provide an enticing, holistic approach into evading the conflicts among its goals, these conflicts 'cannot be shaken off so easily', as they 'go to the historic core of planning and are a leitmotif in the contemporary battles in our cities', rather than being 'merely conceptual, among the abstract notions of ecological, economic, and political logic' (Campbell 1996, p. 296). Even though these goals co–exist uneasily in contemporary cities, sustainable urban development as a long–range objective for achieving the aim of urban sustainability is worthy for urban planners, as they need a strategic process to achieve the status of sustainable cities, to increase the contribution of smart cities to sustainability, and to spur the development of smart sustainable cites. As expressed by Campbell (1996, p. 9), 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. Nevertheless, one can diffuse the conflict, and find ways to avert its more destructive fall–out.' To put it differently, sustainable urban development advocates can—and ought to—seek ways to make the most of all three value–sets at once. This is in contrast to keeping on playing them off against one another. With that in mind, the synergistic and substantive effects of sustainable development on forms of urban management, planning, and development require cooperative effort, collaborative work, and concerted action from diverse urban stakeholders in order to take a holistic view of the complex challenges and pressing issues facing contemporary cities.

In the context of this paper, the focus is on the smart dimension of urban sustainability and sustainable urban development. In this regard, smart urban sustainability consists of four dimensions: physical, environmental, economic, and social, which should be enhanced in terms of goals and be in balance in terms of concerns over the long run—with support of urban computing and ICT—to achieve the sought after smart form of urban sustainability. This can occur through the process of change and strategic approach of sustainable urban development that—in seeking to foster and promote sustainable urban forms, environmental integration, economic development, and social equity as interrelated goals—relies on smart ICT in terms of innovative solutions and novel approaches by unlocking the untapped potential for sustainable transformation that ICT embodies in its morphing and disruptive power as an enabling, integrative, and constitutive technology. The respective change process and strategic approach ought to be driven by linking the research agenda of urban computing innovation and urban ICT development with the agenda of sustainable urban development, thereby justifying ICT investment and its orientation by environmental concerns and socio–economic needs in this context. This endeavor should be supported by pertinent institutional structures and practices.

3.4. Urban Planning and Design

Several notable books (e.g. Jacobs 1961; Lynch 1981; Mumford 1961; McHarg 1995; Wheeler and Beatley 2010) have been written on the subject of urban planning (and development). They have approached it from a variety of perspectives, including social, cultural, political, economic, physical, spatial, and ecological. Urban planning is the process of guiding and directing the use and development of land, urban environment, urban infrastructure, and related ecosystem and human services—in ways that ensure the maximum level of economic development, high quality of life, wise management of natural resources, and efficient operation of infrastructures. In more detail, urban planning entails drawing up, evaluating, and forecasting an organized, coordinated, and standardized physical arrangement of a city and the underlying infrastructural systems, processes, functions, and services, i.e. the built form (buildings, streets, neighborhoods, residential and commercial areas, parks, etc.), urban infrastructure (transportation, water supply, communication systems, distributed networks, etc.), ecosystem services (energy, raw material, water, air, food, etc.), human services (public services, social services, cultural facilities, etc.), and administration (delivery of services and provision of facilities to citizens, implementation of mechanisms for adherence to established regulatory frameworks, policy recommendations, various technical and assessment studies, etc.). The ultimate aim of urban planning is to make cities more sustainable and hence livable and attractive places. As an academic discipline, urban planning is concerned with research and analysis, sustainable development, strategic thinking, environmental planning, transportation planning, land–use planning, landscape architecture, civil engineering, policy recommendations, implementation, administration, and urban design (e.g. Nigel 2007).

Urban design overlaps with urban planning in terms of perspectives and practices. Urban design as an interdisciplinary field involves urban planning, landscape architecture, and civil engineering (Van Assche et al. 2013), in addition to such sub–strands as sustainable urbanism, sustainable urban design, and strategic urban design. Dealing with the design and management of the public domain and the way this domain is experienced and used by urbanites, urban design denotes the process of designing, shaping, and reorganizing cities with respect to physical structures, arrangements, and typologies. The focus in sustainable urban design is on the larger scale of buildings, streets, neighborhoods, districts, parks, public infrastructure, and public spaces, with the primary aim of making urban living more environmentally sustainable and urban areas more attractive and functional (e.g. Aseem 2013; Boeing et al. 2014; Larice and MacDonald 2007; McHarg 1995). In this regard, urban design entails making connections between forms for human settlements and environmental sustainability, economic viability and social equity, the built environment and ecosystems, people and the natural environment, and movement and urban form. These issues are also of interest to the field of urban planning. In the context of this paper, the emphasis is on the smart planning of sustainable urban forms as a set of integrated typologies and design concepts (namely density, compactness, diversity, mixed–land use, sustainable transport, and ecological design) as organized, coordinated, and standardized physical arrangements and spatial organizations. The way cities are designed, developed, and planned is of importance for sustainable development and thus sustainability (e.g. Egger 2006). McHarg (1995) describes and illustrates an ecologically sound approach to urban planning and design, and Wheeler and Beatley (2010) provide a range of perspectives on sustainable urban planning and development.

3.5. Urban ICT and Urban Computing

Information and communication technology (ICT) theory has been applied to almost all human endeavors and thus spheres of society. In the sphere of urban planning and development, the concept of ICT refers to a set of urban infrastructures, architectures, applications, systems, and data analytics capabilities—i.e. constellations of hardware and software instruments across several scales connected through wireless, mobile, and ad hoc networks which provide continuous data regarding the physical, spatiotemporal, infrastructural, operational, functional, and socio–economic forms of the city. These technological components are employed for sensing, collecting, storing, coordinating, integrating, processing, analyzing, synthesizing, manipulating, modeling, simulating, managing, exchanging, and sharing urban data for the purpose of monitoring, understanding, probing, and planning modern cities to achieve particular goals. To put it differently, the aim of applying ICT to urban domains and systems and thus using the underlying core enabling technologies and data–centric applications is to better comprehend how cities function and can be managed as complex systems to derive new theories, devise new solutions, formalize and implement new methods, and study and evaluate processes. This entails a variety of ways of remedying a wide range of problems affecting the long–term health and efficiency of the city as well as the quality of life of its citizens.

At the technical level, urban ICT includes hardware and software components. The former encompass sensors (e.g. RFID, GPS, infrared sensors, smart sensors, wearable devices, etc.), computers and terminals, smartphones, Internet infrastructure, wireless communication networks, telecommunication systems, database systems, cloud computing infrastructure, and middleware architecture. The latter includes all kind of software applications operating and running on these hardware systems, including big data analytics techniques (e.g. data mining, machine learning, statistical analysis, and natural language processing), database integration and management methods, modeling and simulation methods, visualization methods, real–time operation methods, enterprise integration methods, decision support systems, and communication and networking protocols. ICT spans over scores of urban domains and subdomains and hence can be integrated in built form, infrastructure, architecture, networks, facilities, services, spatial organizations, and physical objects, as well as attached to citizens and spread along the trajectories they follow during their daily activities. Urban ICT can be best spoken of based on the context of use, e.g., smart transport, smart mobility, smart traffic, smart energy, smart planning, smart governance, smart environment, smart healthcare, smart education, smart safety, and smart parks (e.g. Bibri and Krogstie 2016a, b).

Urban computing has been used interchangeably with urban ICT; however, there is still a distinction between the two concepts. Drawing on Bibri (2015b), urban ICT theory deals with the application of ICT in and its effects on urban society, and urban computing theory is concerned with the way ICT systems are created and operate in relation to urban planning and design. Entailing a process of big and heterogeneous data collection, integration, analysis, and synthesis (Zheng et al. 2014), urban computing has emerged as a set of computational tools, techniques, and processes to tackle the pressing issues engendered by the rapid urbanization and the challenge of sustainability facing cities by using various kinds of urban data, e.g., human mobility data, spatiotemporal data, traffic flow data, environmental data, energy data, transport data, and socio–economic data. It is an interdisciplinary field where computing as a range of scientific and technological areas (e.g. computer and information science, information technology and systems, computer and software engineering, and wireless and sensor networks) and city–related or urban planning fields (e.g. environmental planning, transportation planning, land use planning, landscape architecture, civil engineering, urban design, ecology, economy, and sociology) converge in the context of urban spaces. Accordingly, urban computing deals with the study, design, development, and implementation of computing technology in urban areas and systems. Specifically, it is concerned with designing and constructing urban–oriented systems and applications and making them behave intelligently as to decision support to serve multiple urban goals; representing, modeling, processing, and managing various kinds of urban data; collecting information and discovering knowledge for various purposes, and so forth. Urban computing employs many of the technological paradigms introduced by the new wave of computing (the integration and large–scale use of various forms of pervasive computing, including UbiComp, AmI, the IoT, and SenComp), i.e. an era when, in the urban context, computer technology in all its forms disappears into urban environments and recedes into the background of urban life, to draw on Weiser (1991). The new wave of computing share the same core enabling technologies, namely sensing devices, computing infrastructures, data processing platforms, and wireless communication networks. These are to function unobtrusively and invisibly in the background of urban life to help improve urban operational functioning, enhance the quality of life, facilitate urban daily activities, understand the nature of urban phenomena, and plan or foresee the future of cities. The new wave of computing is associated with the amalgamation of the most prevalent visions of ICT. For a detailed account of the dominant visions of ICT in terms of their definitions, characteristics, differences, and overlaps, the reader is directed to Bibri and Krogstie (2016b).

3.6. Smart Cities

There are different views regarding the origin of the concept 'smart city' in the literature. According to Gabrys (2014), the roots of the concept date back to the 1960s under what is called the 'cybernetically planned cities', and in urban development plans, it has figured in proposals for networked cities since the 1980s. Dameri and Cocchia (2013) claim that the concept was introduced in 1994. Neirotti et al. (2014) state that the origin of the concept can be traced back to the smart growth movement in the late 1990s. Batty et al. (2012) confirm that it is only until recently that the concept has been adopted in city planning through the movement of smart growth. Speaking of which, it entails increasing urban efficiency with regard to energy, transportation, land use, communication, economic development, service delivery, and so forth. Indeed, a smart city represents essentially efficiency, which is based on intelligent management of urban systems using ICT. Further, it is the period after the emergence of smart city projects supported by the European Union since 2010 that has witnessed a proliferation of writings and academic publications on the topic of smart city (Jucevicius, Patašienė and Patašius 2014).

Nowadays, smart city is a catchphrase that draws increased attention among research institutes, universities, governments, policymakers, and ICT companies. Notwithstanding the wide use of the concept today, there is still unclear and inconsistent understanding of its meaning (e.g. Ahvenniemi et al. 2017; Al Nuaimi et al. 2015; Angelidou, 2015; Batty et al.. 2012; Caragliu, Del Bo, and Nijkamp, 2011; Chourabi et al. 2012; Khan et al. 2015; Marsal–Llacuna et al. 2015; Neirotti et al. 2014; Wall and Stravlopoulos,2016). In view of that, a great number of definitions have been suggested different emphases, although academics, ICT experts, and policymakers converge on the use of ICT across all domains of smart cities, and hence on considering it as an inseparable facet thereof. A wide variety of smart city definitions are available (Albino, Berardi and Dangelico 2015). In addition, smart city has many faces that tend to vary on the basis of such aspects as the way ICT is applied, the digital means by which it is coordinated and integrated, the extensiveness of its use, and the degree of its pervasiveness. These faces include virtual cities, cyber cities, digital cities, networked cities, intelligent cities, knowledge cities, and real–time cities, amongst many other nomenclatures, as well as hybrid cities which combine two or more of these names. Adding to these cities are the ones that are inspired by ICT of various forms of pervasive computing, such as ubiquitous cities, ambient cities, sentient cities, and cities as Internet–of–everything (e.g. Böhlen and Frei 2009; Crang and Graham 2007; Kyriazis et al. 2014; Lee et al. 2008; Shepard 2011; Shin 2009; Thrift 2014). These cities are the object of the next subsection. However, common to all smart cities as urban development strategies or approaches is the idea that ICT is, and will be for many years to come, central to urban operations, functions, services, and designs.

There is no canonical or universally agreed upon definition of smart city. It is a difficult concept to pin down or strictly delineate, and can still be considered a vague notion. It is often context–dependent—i.e. diverse smart city projects, initiatives, and endeavors are based on particular target objectives, available resources, financial capabilities, regulatory and policy frameworks, political structures, and so on. It also depends on the state–of–the–art research and development in the field of ICT as to the available solutions with respect to architectures, technologies, applications, systems, models, methods, computational analytics, and so forth. As an example of target objectives, Batty et al. (2012) identify a number of projects pertaining to smart cities of the future, including mobility and travel behavior; modeling urban land use; integrated databases across urban domains; sensing, networking, and the impact of social media; participatory governance and planning structures; modeling network performance; transport and economic interactions; and decision support as urban intelligence. As regards to the financial capabilities, the growing interest in the concept of smart city, driven by the needs to address and solve urbanization challenges, has led to several investments in ICT development and deployment manifested in the high number of jointly–funded research endeavors as well as smart city initiatives and implementation projects (Ahvenniemi et al. 2017). In all, it is evident that smart city lacks a shared definition, and thus it is hard to identify common trends.

In essence, there are two mainstream approaches to smart city: (1) the technology and ICT–oriented approach and 2) the people–oriented approach. Specifically, there are smart city strategies which focus on the efficiency and advancement of hard infrastructure and technology (transport, energy, communication, waste, water, etc.) through ICT, and strategies which focus on the soft infrastructure and people, i.e. social and human capital in terms of knowledge, participation, equity, safety, and so forth (Angelidou 2014). As an example of the first approach, Kitchin (2014) conceives of smart city as one that monitors and integrates all of its critical infrastructures, optimizes its resources, plans its activities, and maximizes services. In this line of thinking, Marsal–Llacuna et al. (2015) state that by using ICT and data analytics technologies, smart cities aim to monitor and optimize existing infrastructure, to increase collaboration among economic actors, to provide more efficient services to citizens, and to support innovative business models across private and public sectors. As to the second approach, Neirotti et al. (2014) describe smart city as a way of enhancing the life quality of citizens. Smart city entails human and social factors, apart from physical and technological factors (Aguilera et al. 2013). Lombardi et al. (2011) emphasize additional soft factors such as participation, safety, and cultural heritage. Other views tend to put emphasis on services (e.g. Belanche, Casaló, and Orbs 2016; Lee, Hancock and Hu 2014). Belanche, Casaló, and Orbs (2016) underscore the increased use of urban services to attain efficiency and sustainability. Angelidou (2014) underscores the role of ICT to achieve prosperity, effectiveness, and competitiveness.

It is important to highlight the body of the literature focusing on the role of human and social capital, in addition to new technologies, in developing smart cities that aim to improve economic, social, and environmental sustainability (e.g., Batty et al. 2012; Giffinger et al. 2007; Hollands 2008; Nam and Pardo 2011; Neirotti et al. 2014). This stream of literature is concerned with smart cities as urban innovations based on ICT that aims at harnessing physical and social infrastructures as well as natural and knowledge resources for economic regeneration, environmental efficiency, and public and social service enhancement. One of the most cited definitions in this regard is the one advanced by Caragliu, Del Bo and Nijkamp (2009, p. 6), which 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.' This definition is based on a model that has been used as a classification system—developed through six distinct dimensions, namely smart mobility, smart environment, smart living, smart people, smart economy, and smart governance—against which smart cities can be gauged or evaluated in terms of their development in the direction of smartness. This model is said to represent a holistic understanding by what it entails in terms of the complementary nature of these dimensions. Though it doesn't provide a prioritization of these dimensions as to their contribution to sustainability, nor does it specify how they can add to urban development and planning practice in terms of sustainability. Nevertheless, this connotation of smart city is seen as a strategic devise to highlight the growing role and potential of ICT in enabling and catalyzing sustainable urban development processes. Indeed, it goes beyond technological investments and advancements to include environmental, social, and economic developments with sustainability in mind. In extending this definition, Pérez–Martínez et al. (2013, cited in Ahvenniemi et al. 2017) 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 a similar vein, Batty et al. (2012, p. 481 482) conceive of smart cities as cities 'in which ICT is merged with traditional infrastructures, coordinated and integrated using new digital technologies', and where 'intelligence functions…are able to integrate and synthesize…[urban] data to some purpose, ways of improving the efficiency, equity, sustainability, and quality of life in cities.' In all, smart cities endeavor to amalgamate advanced digital technologies and urban planning approaches to find innovative and smart solutions that contribute to improving livability and enhancing sustainability (see Toppeta 2010). Smart initiatives can be used to promote environmental sustainability (Kramers et al. 2014). This implies that sustainability is not an integral part of all the definitions of smart city. This is taken up as a research issue in the next section.

3.7. Smarter Cities

The increasing convergence, prevalence, and advance of urban ICT is giving rise to new faces of cities that are quite different from what has been experienced hitherto on many scales. These cities are labelled 'smarter cities' because of the magnitude of ICT and the profusion of data as to their embeddedness and use in urban systems and domains. The prospect of smart cities getting smarter is becoming the new reality with the massive proliferation of sensing, computing, data processing, communication, and networking technologies across various spatial scales. Smarter cities include ubiquitous cities (e.g. Batty et al. 2012; Lee et al. 2008; Shin 2009), ambient cities (e.g. Böhlen and Frei 2009; Crang and Graham 2007), sentient cities (e.g. Shepard 2011; Thrift 2014); and cities as an Internet of everything (e.g. Kyriazis et al. 2014). They are seen as future forms of smart cities. The initiatives of smarter cities enabled by ICT of various forms of pervasive computing (namely UbiComp, AmI, SenComp, and the IoT) in several countries across Europe, the USA, and Asia are increasingly considered as national urban development projects that center on strengthening the role of ICT, especially big data analytics and context–aware computing, in urban operations, functions, services, and designs as to management, planning, and development to advance urban sustainability (Bibri and Krogstie 2016a).

In light of the above, the concept of smarter cities is built upon the core characteristic features of the prevalent ICT visions in terms of the ubiquity of computing in urban systems, massive use of ICT in urban domains, and its numerous benefits and opportunities for cities and citizens. That is, the pervasion of sensors technologies, information processing systems, and computational analytics and communication capabilities into urban environments and thereby the omnipresence and always–on interconnection of computing resources and services across many spatial and temporal scales, to draw on Bibri (2015a). Accordingly, the conceptualization of smarter cities is associated with the ever–growing and deep embeddedness of advanced ICT into the very fabric of the city in terms of operations, functions, designs, and services. It indeed differentiates smarter cities as emerging and future cities from the aforementioned conceptualizations of common smart cities. In this respect, Townsend (2013, p. 15) defines a smart city as an urban environment where ICT 'is combined with infrastructure, architecture, everyday objects, and even our own bodies to address social, economic and environmental problems.' Piro et al. (2014, p. 169) describe it 'as an urban environment which, supported by pervasive ICT systems, is able to offer advanced and innovative services to citizens in order to improve the overall quality of their life.' According to Su, Li and Fu (2011), a smart city mainly focuses on embedding the next–generation of ICT into every conceivable object or all walks of life, including roads, railways, bridges, tunnels, water systems, buildings, appliances, hospitals, and power grids, in every corner of the world, and constituting the IoT. Chourabi et al. (2012) define a smart city as a city which strives to become smarter in the sense of making itself more efficient, livable, equitable, and sustainable. Here the word 'smarter' implies the use of advanced ICT in order to improve efficiency, sustainability, equity, and the quality of life. This is in line with what constitutes smart cities of the future according to Batty et al. (2012). The basic idea is that future smart cities have greater potential than existing smart cities for advancing their contribution to the goals of sustainable development. This is due to the current capabilities as well as the prospective advancements pertaining to big data analytics and context–aware computing as advanced forms of ICT, in addition to their increasing amalgamation in various urban domains and systems in terms of the underlying core enabling technologies, namely sensor devices, computing infrastructures, data processing platforms, and wireless communication networks (e.g. Al Nuaimi et al. 2015; Batty et al. 2012; Bibri and Krogstie 2016b; Böhlen and Frei 2009; DeRen, JianJun and Yuan 2015; Kamberov 2015; Khan, Anjum and Kiani 2014; Khan et al. 2015; Shepard 2011; Solanas et al. 2014). In all, a smarter city can be described as a city where advanced ICT is combined with physical, infrastructural, architectural, operational, functional, and ecological systems across many spatial scales, as well as with urban planning approaches, with the aim of improving efficiency, sustainability, equity, and livability. Smarter cities entail that diverse context–aware and big data applications operating across cloud computing infrastructures can monitor what is happening in urban environments (in terms of situations, events, activities, processes, behaviors, locations, spatiotemporal settings, environmental states, socio–economic patterns, and so on) and process, analyze, interpret, visualize, and react to the outcome through decision support systems and strategies at varying ways—be it in relation to smart energy, smart grid, smart street and traffic lights, smart transport, smart mobility, smart healthcare, smart education, smart safety, smart planning, smart governance, or smart buildings—across many spatial scales (Bibri and Krogstie 2016b). Here, smartness should primarily be focused on the goals of sustainable development rather than on only technology and the efficiency of smart solutions. There has been a shift in cities striving for smartness targets instead of sustainability goals (Marsal–Llacuna, Colomer–Llinàs and Meléndez–Frigola 2015).

3.8. Sustainable Cities: Sustainable Urban Forms

There are various definitions of what a sustainable city should be. Based on the literature on compact city and eco–city as the most prevalent models of sustainable city (e.g. Hofstad 2012; Jenks, Burton and Williams 1996a, b; Joss 2010; Girardet 2008; Rapoport and Vernay 2011; Williams 2009), a sustainable city can be understood as a set of approaches into practically applying the knowledge of urban sustainability and environmental technologies to the planning and design of existing and new cities or districts. In the context of this paper, a sustainable city can be described as an urban environment designed with the primary aim of contributing to improved environmental quality and protection and social equity and well–being over the long run, which can be attained through adopting sustainable development strategies to foster advancement and innovation in urban infrastructure, urban operational functioning, urban management, ecosystem service provision, and human service provisioning, while continuously optimizing efficiency gains. This entails working strategically towards mitigating the environmental impacts derived from the intensive consumption of energy, while promoting social justice, safety, and stability. In more detail, sustainable cities strive to maximize efficiency of energy and material resources, create a zero–waste system, support renewable energy production and consumption, promote carbon–neutrality and reduce pollution, decrease transport needs and encourage walking and cycling, provide efficient and sustainable transport, preserve ecosystems, emphasize design scalability and spatial proximity, and promote livability and sustainable community.

Sustainable development has significantly impacted the development of city models in terms of different dimensions of sustainability (e.g. Jabareen 2006; Hofstad 2012; Joss 2011; Girardet 2008; Williams, Burton and Jenks 2000). Unquestionably, it has inspired and motivated a generation of urban scholars and practitioners into a quest for the immense opportunities enabled and created by the development of sustainable urban forms—i.e. the contribution that these forms can make as to lowering energy use and lessening pollution and waste levels, while improving human life quality and well–being. Therefore, the idea of applying the concept of sustainable development to urban form has intensively been investigated and discussed by researchers and planners during the last decade (see Kärrholm 2011). According to Lynch (1981, p. 47), urban form is 'the spatial pattern of the large, inert, permanent physical objects in a city.' In more detail, urban form as aggregations of repetitive elements denotes amalgamated characteristics pertaining to land use patterns, spatial organizations and other urban design features, as well as transportation systems and environmental and urban management systems (Handy 1996; Williams**,** Burton and Jenks 2000). A sustainable urban form can be conceived of as an urban form for human settlements that seeks to meet the required level of sustainability by enabling the urban systems (built form, infrastructure, ecosystem services, human services, and administration) and thus the urban domains to function in a constructive way (Bibri and Krogstie 2017). Using a thematic analysis approach, Jabareen (2006) classifies sustainable urban forms into four models entailing overlaps in their concepts and ideas: (1) compact city, which emphasize density, compactness, and integrated/mixed–land use; (2) eco–city, which focuses on ecological diversity, passive solar design, renewable resources, ecological design, and environmental management; (3) neo–traditional development or new urbanism, which is characterized by sustainable transport, mixed–land use, diversity, compactness, and ecological design; (4) and urban containment, which centers on policies of compactness. This paper is concerned with the first three urban forms in terms of integrating the underlying (relevant) typologies and design concepts as well as environmental and urban management systems with ICT of the new wave of computing in the context of smart sustainable cities of the future. From a general perceptive, a typology refers to the grouping of 'artifacts describing different aspects of the same or shared characteristics' (Bibri 2015a, p. 31). For a detailed account and discussion of the typologies as well as design concepts of sustainable urban forms, the reader is directed to Jabareen (2006).

3.9. Smart Sustainable Cities

The smart sustainable city is a new techno–urban phenomenon. Hence, the term only became widespread during the mid–2010s (e.g. Al−Nasrawi, Adams and El−Zaart 2015; Bibri and Krogstie 2016a, b; Höjer and Wangel 2015; Kramers, Wangel and Höjer 2016; Rivera, Ericsson and Wangel 2015) as a result of several intertwined global shifts. The interlinked development of sustainability awareness, urban growth, and technological development have recently converged under what is labelled 'smart sustainable cities' (Höjer and Wangel 2015). The concept has emerged on the basis of five different developments, namely sustainable cities, smart cities, urban ICT, sustainable urban development, sustainability and environmental issues, and urbanization and urban growth (Höjer and Wangel 2015). The term 'smart sustainable city', although not always explicitly discussed, is used to denote a city that is supported by a pervasive presence and massive use of advanced ICT, which, in connection with various urban domains and systems and how these intricately interrelate, enables cities to become more sustainable and to provide citizens with a better quality of life. In more detail, it can be described as a social fabric made of a complex set of networks of relations between various synergistic clusters of urban entities that, in taking a holistic and systemic approach converge on a common approach into using and applying smart technologies that enable to create, disseminate, and to mainstream solutions and methods that help provide a fertile environment conducive to improving the contribution to the goals of sustainable development. Here, ICT can be directed towards and effectively used for collecting, analyzing, and synthesizing data on every urban domain and system involving forms, structures, infrastructures, networks, facilities, services, and citizens. And these data can be utilized to develop urban intelligence functions as well as build urban simulation models to gain deep and predictive insights for strategic decision–making associated with sustainability. The combination of smart cities and sustainable cities, of which many definitions are available, has been less explored as well as conceptually difficult to delineate due to the multiplicity and diversity of the existing definitions. ITU (2014) provides a comprehensive definition based on analyzing around 120 definitions, 'a smart sustainable city is an innovative city that uses…ICTs and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects.' Another definition put forth by Höjer and Wangel (2015, p. 10), which is deductively crafted and based on the concept of sustainable development, states that '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 as a critical driver for environmental, social, and economic development, where ICT is conceptualized as an enabling and constitutive technology, thereby its transformational effects as to addressing the challenge of urban sustainability.

4. Related Research Work and Key Issues, Debates, and Challenges

In the emerging field of smart sustainable cities, research is inherently interdisciplinary and remarkably heterogeneous, and thus involves a plethora of issues, debates, and challenges that need to be addressed. This is essential for identifying new research opportunities and hence embarking on research endeavors on the basis of what has been investigated as questions and problems to date. The ultimate aim is to develop novel integrated frameworks or convincing comprehensive models that can play a role in spurring the development of smart sustainable cities, which aim at achieving their full potential in terms of the required level of sustainability and the integration of its dimensions. Successful frameworks are models are to have a high replicative capacity favorable to mainstreaming the needed transition to smart sustainable urban planning and development.

4.1. Smart (and Smarter) Cities

It is useful to point out that most of the issues, debates, and challenges discussed here in relation to smart cities apply, by extension, to smarter cities.

4.1.1. Research Strands

The topic of smart cities brings together a large number of previous studies, including research directed at conceptual, analytical, and overarching levels, as well as research on specific technologies and their potentials and opportunities. Indeed, recent years have witnessed a great interest in and a proliferation of academic publications on the topic of smart cities. This reflects the magnitude and diversity of research within the field. The existing body of research is rapidly burgeoning, where the emphases and aims tend to be varied, as manifested in researchers' miscellaneous contributions to the conceptualization, design, development, and implementation of smart cities. From a general perspective, the field of smart cities merges broad streams of scholarship, which entail various strands of research. One strand of research is concerned with the theory and practice of urban computing, applied urban science, and urban ICT. This line of work addresses questions pertaining to urban sensing, urban informatics, big data analytics, context–aware computing, cloud computing infrastructures, data processing platforms, urban simulation models and intelligence functions, database integration, wireless technologies and networks, decision support systems, and so on. These varied technologies are applied to diverse urban domains (e.g. transport, mobility, energy, environment, water, waste, planning, design, education, healthcare, safety, governance, and economy) to achieve efficiency and better management (e.g. Angelidou 2014; Batty 2013a, b; Batty et al. 2012; Belanche, Casaló, and Orbs 2016; ChuanTao et al. 2015; DeRen, JianJun and Yuan 2015; Gonzales and Rossi 2011; Harrison and Donnely 2011; Hung–Nien et al. 2011; Jucevicius, Patašienė and Patašius 2014; Khan et al. 2015; Kitchin 2014; Lombardi et al. 2011; Marsal–Llacuna et al. 2015; Paroutis, Bennett and Heracleous 2013; Piro 2014; Townsend 2013; Zheng et al. 2014). This strand of research focuses mainly on technological advancement, use, and application for efficiency and management purposes, which tend to prevail in the field of smart cities. Our study is rather concerned with the role of ICT in advancing urban sustainability, in particular in relation to smarter cities as future faces of smart cities and their integration with existing sustainable cities.

Remaining on the same strand of research, a large body of conceptual work on smart cities has attempted to develop definitions and models to provide both a joint understanding of the concept of smart city, as well as a basis for further discussions on what this urban development approach aspires to deliver as to different aspects of smartness, though with less emphasis on sustainability. Adding to this academic endeavor is a large body of analytical work which has endeavored to investigate numerous propositions—in the light of emerging and future ICT—about what makes a new city badge or an existing city regenerate itself as smart, why a city uses ICT to develop new urban intelligence functions, and how a city develops urban services using modern ICT, among other things. Accordingly, early research work has tended to conceptualize, describe, classify, or rank the phenomenon of smart city based on the use of modern ICT in relation to a wide variety of urban operations, functions, designs, and services. Whereas recent research has typically focused on analyzing different projects, prospects, and initiatives and their possible urban impacts, with an emphasis on specific technologies and their applications, such as big data analytics, urban informatics, context–aware computing, and cloud computing, along with the challenges involved in achieving various smart city statuses. It is worth noting that, as this literature shows, there is a great deal of diversity among smart cities, and in this sense, it is pertinent to view the smart city as an ambition which can be for varied objectives and shaped by diverse disruptive technologies, and which there will be multiple ways to achieve. Of importance to underscore in this regard is that the so–called advanced ICT is sometimes used without any contribution to sustainability.

Another strand of research looks at the impacts ICT has on how we think about and conceive of cities in the sense of propelling us to rethink or alter some of the core concepts through which we analyze, operate, organize, assess, plan, and value urban life towards creating more sustainable ways of dwelling in and interacting with urban environments (e.g. Al Nuaimi et al. 2015; Batty et al. 2012; Böhlen and Frei 2009; Shepard 2011; Solanas 2014). A key line of work within this strand tends to focus on integration proposals from a more conceptual perspective. The underlying idea is that some smart city approaches can be combined with some sustainable city models (e.g. Al−Nasrawi, Adams and El−Zaart 2015; Höjer and Wangel 2015; Kramers et al. 2014), or the other way around. In the latter case, the aim evolves around enhancing the contribution of sustainable cities to sustainability with support of smart ICT. This is anchored in the underlying assumption that ICT is founded on the application of the complexity and data sciences which help to address the complex challenges and problems of sustainability. This tends, though, to involve mostly the infrastructural, operational, and functional aspects of sustainable cities, rather than the physical and spatial facets in terms of integrating them with technologies for better understanding, analysis, assessment, and planning purposes. Indeed, any kind of integration involving smart ICT and sustainable development requires a holistic approach into enabling cities to realize their potential as to their contribution to sustainability. In this regard, cities that stand on a spectrum of the sustainability scale can embrace and exploit smart development initiatives. By the same token, cities that stand on a spectrum of the smartness scale can embrace and exploit sustainable development initiatives. In this line of thinking, recent research endeavors (e.g. Al Nuaimi et al 2015; Batty et al. 2012; Ahvenniemi et al. 2017) have started to focus on how to enhance smart city approaches in an attempt to achieve the required level of sustainability with respect to urban operations, functions, services, and designs. The best cities are those that support the generation of creative ideas and, more importantly, promote sustained development (Jacobs 1961). Besides, for existing smart cities to thrive, they need to leverage their informational landscape in ways that enable them to incorporate and sustain their contribution to sustainability. In all, the main premise underlying the recently suggested integration proposals is to highlight that smart cities hold great potential to advance urban sustainability—if ICT advancement, use, and application can be directed for this goal. As smartness targets and sustainability goals are interconnected and thus smart cities tend to share similar goals as sustainable cities (Ahvenniemi et al. 2017), it is important to understand the link between the concepts of smart city and sustainable city (Bifulco et al. 2016), to iterate.

Another strand of research, which relates to the above one, focuses on the deficiencies or inadequacies associated with the sustainability of smart cities. The main issue being addressed and discussed is that not all the definitions of smart city incorporate the goals of sustainable development. According to Höjer and Wangel (2015), the existing concepts of smart city set up no baseline for sustainability, nor do they define what sustainable development is, although defining this concept is crucial to know the purposes for which smart ICT should be used, as well as to assess whether (or the extent to which) smart ICT contributes to the goals of sustainable development or delivers the desired outcomes in this regard. As echoed by Kramers et al. (2014), the concept of smart city says little about how any substance behind the smart solutions links to sustainability, and particularly has little to do with environmental concerns or solutions. In line with this thinking, in studying the concept of smart city through a lens of strategic sustainability, Colldahl, Frey and Kelemen (2013) argue that while the concept of smart city is a powerful approach into enabling cities to become sustainable due to its potential to address some sustainability challenges by improving efficiency in urban systems, in addition to having an innovative and forward–thinking approach to urban planning, it is currently associated with shortcomings with regard to sustainability, i.e. it ‘does not necessarily allow for cities to develop in a sustainable manner’. And there are various approaches that can be espoused to mitigate these shortcomings so that smart cities can evolve towards sustainability in a more effective way. One of which is to endeavor to explicitly incorporate the goals of sustainable development in the concept of smart city and to work towards developing smart cities in ways that direct ICT development and innovation towards primarily increasing their contribution to these goals. Especially, topical studies have highlighted the need for smart cities to pursue this path, and have also called for caution when encountering current smart city initiatives. In a very recent study, Ahvenniemi et al. (2017) used 16 existing smart city and sustainable city assessment frameworks (8 related to sustainable city and 8 related to smart city) to examine how smart cities compare with sustainable cities as to both commonalities and differences. They compare these frameworks as performance measurement systems with respect to 12 application domains (namely natural environment; built environment; water and waste management; transport; energy; economy; education, culture, science and innovation; well–being; health and safety; governance and citizen engagement; and ICT) and 3 impact categories (environmental, economic, and social sustainability) involving 958 indicators altogether. The authors observe a much stronger focus on modern ICT and what it entails in terms of smartness in the smart city frameworks as to social and economic indicators, but a lack of environmental indicators. They conclude that smart cities need to improve their sustainability with support of advanced ICT, and suggest on the basis of the gap between smart city and sustainable city frameworks further development of smart city frameworks and redefinition of the concept of smart city. Accordingly, they suggest that the assessment of smart city performance should use impact indicators that measure the contribution of smart cities to sustainability and thus to the environmental, economic, and social goals of sustainable development. Kramers et al. (2014) suggest that the concept of smart sustainable city can be used when as a way of emphasizing initiatives where smartness is directed towards promoting environmental sustainability. As supported by Höjer and Wangel (2015), smart cities become sustainable when ICT is employed for improving sustainability.

Much of the aforementioned technical literature on smart cities focuses on specific technologies and their potentials and opportunities. Specifically, the state of research in the realm of smart cities—a burgeoning scholarly interdisciplinary field and science–based, techno–urban enterprise—shows varied focuses of topical studies as to the potential of new technologies and their novel applications and services. This entails bringing advanced solutions for diverse complex problems related to such urban domains as transport, mobility, environment, energy, science and innovation, governance, and economy, as well as providing a plethora of new online and mobile services to citizens to improve the quality of their life with respect to education, healthcare, safety, well–being, accessibility, participation, and so forth. However, while ICT progress in this regard is rapid and manifold, it seems to happen ad hoc in the context of smart cities when new technologies and their applications become available, rather than grounded in a theoretically and practically focused overall approach—e.g. the most needed and urgent solutions that ICT can offer in the context of sustainability as an overarching urban application domain. In addition, to develop smart solutions of less relevance to environmental concerns and socio–economic needs is not the most effective way of driving ICT development and innovation in the context of smart cities. What is alternatively, needed, or rather what smart solutions ought to be created for, is a realistic tackle of the most pressing problems (e.g. energy inefficiency, environmental inefficiency, urban isolation, social injustice, and inaccessibility to opportunities). As to energy efficiency, for instance, Kramers et al. (2014) argue that the available opportunities need to be explored thoroughly and investigated as to how they can best support the implementation of ICT solutions to turn the potentials into real energy savings, and concurrently ICT industry needs to learn how best to design and implement the so–called smart solutions that lower energy usage. However, at this stage, there is much focus on technical dimensions as to ICT development and innovation, which pertains to all existing smart city approaches. Moreover, smart cities are associated with shortcomings in terms of lacking a holistic orientation as to integrating environmental, economic, and social considerations and goals of sustainability with technological opportunities. Hence, it is high time to link technological progress with the agenda of sustainable development and thus to justify future ICT investments by environmental concerns and socio–economic needs in the context of smart cities.

4.1.2. Scientific Challenges and Environmental and Social Risks

There are numerous and diverse challenges facing existing and future smart cities. Here the focus is on the most relevant ones in the context of our study. With reference to smart cities of the future, Batty et al. (2012, p. 481–482) identify and elucidate several scientific challenges, namely 'to relate the infrastructure of smart cities to their operational functioning and planning through management, control and optimization; to explore the notion of the city as a laboratory for innovation; to provide portfolios of urban simulation which inform future designs; to develop technologies that ensure equity, fairness, and realize a better quality of city life; to develop technologies that ensure informed participation and create shared knowledge for democratic city governance; and to ensure greater and more effective mobility and access to opportunities for urban populations.'

Furthermore smart cities pose many risks to environmental sustainability (e.g. Bibri and Krogstie 2016a; Greenfield 2013; Hollands 2008) due to the ubiquity of computing and the massive use of ICT across urban domains and systems. Driving this line of research are questions involving the way smart cities should measure and identify risks, uncertainties, and hazards (e.g. Batty et al. 2012) associated with ICT and set safety standards. This pertains not only to environmental sustainability, but also to social sustainability with regard to equity, fairness, participation, privacy, security, digital divide, and so on (e.g. Colldahl, Frey and Kelemen 2013; Hollands 2008; Murray, Minevich and Abdoullaev 2011). But the most eminent threat of ICT in the context of smart cities lies in its multidimensional effects on the environment (e.g. Bibri and Krogstie 2016a). The real challenge lies in estimating the potential for curbing energy usage in a meaningful way in the sense of mitigating concomitant environmental impacts. The underlying assumption is that ICT as an enabling and constitutive technology is embedded into a much wider socio–technical landscape (economy, institutions, policy, politics, and social values) in which a range of factors and actors other than techno–scientific ones are involved (Bibri and Krogstie 2016a). Therefore 'without careful implementation in combination with other measures, ICT solutions might also result in increased energy use instead of a reduction, either directly or in other parts of the energy system… [I]n order to establish the full impact of implemented ICT solutions, it is important to take into account all direct and indirect changes resulting from this, including the impact from the ICT solution's entire lifecycle. This also points to the importance of combining its implementation with policy and planning instruments, so as to ensure that the efficiency gains actually lead to a reduced use of energy.' (Kramers et al. 2014, p. 60)

4.1.3. Smart City Frameworks and Infrastructures

While the literature shows a diversity of smart city frameworks, the one developed by Giffinger et al. (2007): the European Smart Cities Ranking, remains the most widely quoted, used, and applied in the field. It has been developed to enable the comparison of cities and to assess their development towards the needed direction. Accordingly, it has been used as a classification system—based on six distinct dimensions, namely smart mobility, smart environment, smart living, smart people, smart economy, and smart governance—against which smart cities can be gauged. Each dimension comes with a set of factors or criteria that evaluate success under that dimension. In this regard, a city identifies, based on the examination of its current state of smart development, the areas that might necessitate further improvements and then attempt to meet the necessary conditions so as to be able to regenerate itself as smart. In doing so, it can set goals based on its unique circumstances by pursuing the six dimensions in terms of related visions or prospects (Giffinger et al. 2007; Steinert et al. 2011). Other smart city frameworks (e.g. Chourabi et al. 2012; Correia and Wuenstel 2011; Neirotti et al. 2014) tend to differ slightly from the aforementioned one by combining, rearranging, extending, or renaming the defining characteristics or constituting features (i.e. relevant application domains) of smart cities. There are also other smart city performance assessment systems, such as Albino et al. (2015), Lazaroiu and Roscia (2012), and Lombardi et al. (2012).

Another set of frameworks has been developed for certain urban domains. In this regard, some frameworks have been proposed to benchmark cities and to assess the smartness of their transportation systems (e.g. Debnath et al. 2014; Garau, Masala, and Pinna 2016), urban mobility (e.g. Garau, Masala, and Pinna 2015), environment (e.g. Neirotti et al. 2014), or quality of life (e.g. Khan et al. 2015). In relation to sustainability, Ahvenniemi et al. (2017, p. 235) state, quoting, Marsal–Llacuna et al. (2015) , 'the smart city assessment builds on the previous experiences of measuring environmentally friendly and livable cities, embracing the concepts of sustainability and quality of life but with the important and significant addition of technological and informational components'. A study conducted by Bifulco et al. (2016) addresses the connections between the technologies enabling the smart city characteristics as conceptualized in the framework proposed by Giffinger et al. (2007) and the goals of sustainability. While the authors outline a new research avenue for the development of frameworks that amalgamate ICT with sustainability in, and new indicators for the evaluation of, smart interventions, no details are provided as to how to develop such frameworks in terms of the technological and urban components needed to achieve the purpose.

In addition, a wide variety of smart city infrastructures (e.g. Al–Hader and Rodzi 2009; DeRen JianJun and Yuan 2015; Khan et al. 2012; Khan et al. 2015; Khan and Kiani 2012; Khan, Pervez and Ghafoor 2014; Kiani and Soomro 2014; Nathalie et al. 2012) have been proposed and some of them have been applied in recent years. These infrastructures are based on cloud computing and tend to focus on technological aspects (especially big data analytics, context–aware computing, development and monitoring, etc.), urban management, privacy and security management, or citizen services in terms of the quality of life. There have been no research endeavors undertaken to develop comprehensive or integrated smart city infrastructures for addressing the challenge of sustainability. But there have been some attempts to address some aspects of environmental sustainability. For example, Lu et al. (2011) propose a framework for multi–scale climate data analytics based on cloud computing. Speaking of the climate in this context, there is still a risk of a mismatch between urban climate targets and the opportunities offered by ICT solutions (Kramers et al. 2014).

4.2. Sustainable Cities

4.2.1. Research Strands

There is a large body of work available on sustainable cities. The field is remarkably heterogeneous, entailing a diversity of research questions and problems that have been addressed to date in the context of urban sustainability. Thus, the topic of sustainable cities brings together a large number of previous studies, including research directed at conceptual, analytical, philosophical, and overarching levels, as well as specific research on urban forms and their typologies, design concepts, and models and their opportunities for improving sustainability. Since the application of sustainable development to urban planning and development in the early 1990s, many scholars and practitioners from different disciplines (urban planning, urban design, urban morphology, ecology, architecture, etc.) all have come to recognize and advocate that understanding and recalibrating the urban form and functioning of cities were crucial to developing a more sustainable urban future.

One strand of research on sustainable cities focuses on issues around the theory of sustainable urban planning (e.g. sustainable urban forms) and the effects of its application on cities. Typically, the sustainability of cities has been concerned with sustainability effects taking place within cities' boundaries (Höjer and Wangel 2015). This pertains to the underlying theory of urban sustainability and its application as a foundation for urban practice (e.g. Williams 2009), particularly in relation to eco–city (e.g. Girardet 2008; Joss 2011; Joss, Cowley and Tomozeiu 2013; Rapoport and Verney 2011; Register 2002; Roseland 1997) and compact city (e.g. Jenks, Burton and Williams 1996a, b; Neuman 2005; Hofstad 2012) as the most prevalent models of sustainable urban form (see, e.g., Jabareen 2006; Kärrholm 2011). The theory of sustainability has particularly been influential in how the subject of contemporary cities, in particular the built environment, has been studied and applied. As this theory is more normative, institutional, and philosophical, it is more open to re–interpretation, re–evaluation, or critical examination. Indeed, in urban practice not all the challenges and solutions pertaining to sustainable urban planning can be identified (Höjer and Wangel 2015). And even the identified ones are usually not completely addressed and applied —urban problems are obviously of wicked sorts. In all, this strand of research is concerned with the implication of the theoretical underpinnings of sustainable urban planning, and to what extent this foundation delivers what is claimed. This entails questions aimed at challenging theoretical assumptions, discovering contradictions and weaknesses, identifying gaps and omissions, revealing fallacies, substantiating implications, and examining broad issues.

Remaining on the same strand of research and at the abstract and intellectual level, a large body of work tends to focus on the concepts and theories underpinning the thinking about the subject of sustainable city. This body includes analyzing discourses of urban planning and development and how decisions are made (e.g. Kumar and Pallathucheril 2004; Portugali and Alfasi 2008). Related issues pertain to the definition of theoretical terms and discursive notions as well as different understandings and constructions, and how these are germane to the subject of sustainable city (e.g. Bibri and Bardici 2015; Dryzek 2005; Hajer 1995; Rapoport and Verney 2011). This is because this subject has a theoretical base that is open to interpretation, evaluation, and examination, or in it, theoretical debate seems to be rife and a key aspect of the discipline of sustainable urban planning. Having a practical application, the subject of city within this discipline relies on theoretical assumptions and foundations. And it requires environmental, social, and economic issues to be addressed (e.g. Bulkeley and Betsill 2005; Hofstad 2012; McHarg 1995; Register 2002), as well as institutional priorities and technological considerations (e.g. Bibri and Krogstie 2016a; Bibri and Krogstie 2017) to be set apart from theoretical matters of urban planning and development as internally consistent models or uniquely coupled with their distinct characteristics. In all, this research strand is concerned with comparing and evaluating concepts and approaches, weighing up arguments, rethinking issues, and challenging discursive assumptions—see examples relating to the topic of the social shaping dimensions of sustainable cities (Bibri and Krogstie 2016a).

Another strand of research on sustainable cities entails a large body of analytical work. This academic endeavor focuses on investigating different propositions (models of problems and solutions) about what makes a city, or how it can be made, sustainable (e.g. Bibri and Bardici 2015; Girardet 2008; Hofstad 2012; Jenks and Dempsey 2005; Jabareen 2006; Joss 2011; Kärrholm 2011; Neuman 2005). Most of the analytical work carried out on sustainable cities entails exploring approaches to planning and development that combine various aspects of the city, including spatial organizations, urban infrastructures, urban environmental and management systems, ecosystem services, and green and energy efficiency technologies. A recent wave of this work involves sustainable initiatives that tend to focus on technical solutions (smart ICT) for making urban metabolism more efficient (e.g. Shahrokni et al. 2015). Here, urban metabolism as a framework serves to determine and maintain the levels of sustainability and health of urban forms, and thus its application is intended for sustainability reporting and urban design. From a general perspective, sustainable city development has, over the last two decades or so, emerged as a response to the challenge of sustainability. Accordingly, an array of the so–called models of sustainable urban form (e.g. compact city, eco–city, and new urbanism) has been developed to address the rising concerns about the environment, predominately. This is because the form of contemporary cities has been perceived mostly as a source of environmental problems (Alberti et al. 2003; Beatley and Manning 1997; Hildebrand 1999b; Newman and Kenworthy 1989). However, of the existing models, compact city and eco–city have been seen as the preferred ones as to contributing to the goals of sustainable development (see, e.g., Hofstad 2012; Joss, Cowley and Tomozeiu 2013). Sustainable urban forms can be achieved by a combination of such typologies as density, compactness, diversity, and mixed–land use, supported by sustainable transport, ecological design, and solar passive design as design concepts, as well as advanced environmental and urban management systems (see Jabareen 2006). Furthermore, several studies (e.g. Guy and Marvin 2000; Joss 2010; Jabareen 2006; Kärrholm 2011; Rapoport and Vernay 2011) point to the issue of diversity with regard to the usages of the terms describing existing models of sustainable urban form, as well as that of the extent of convergence or divergence in the way in which different projects, initiatives, and plans pertaining to each model prescribe the approach into achieving that model, or conceive of how that model should look like. There is a great deal of heterogeneity among city initiatives or urban projects that are considered to be sustainable cities. This goes beyond their ambition to include their vision of what the future of sustainable urban development should entail. The alphabet soup of sustainable city projects and initiatives has generated a cacophony leading to an exasperating confusion in the field of sustainable urban development.

In all, whether in discourse, theory, or practice, the issue of sustainable urban form has been problematic and difficult to deal with, resulting in uncertain, different, and contradictory results (Kärrholm 2011). Regardless, conceiving cities in terms of forms remains inadequate to achieve the goals ascribed to sustainable urban forms; rather, conceiving these forms in terms of 'processual outcomes of urbanization' holds great potential for attaining the goals of sustainable development (Neuman 2005). Important to note here is that there is a mutually beneficial relationship between urbanization and ICT development. In this regard, cities need to be scalable in design and flexible and resilient in their functioning in response to urban growth, environmental pressures, and changes in socio–economic needs. This paves the way for dynamic conception of urban planning that reverses the focus on urban forms governed by static planning tools (Neuman 2005). Thus far, in urban planning and policy making, 'the concept of sustainable city has tended to focus mainly on infrastructures for urban metabolism—sewage, water, energy, and waste management within the city' (Höjer and Wangel 2015, p. 3), thereby falling short in considering other urban domains where smart solutions can have a substantial contribution. In fact, in light of the recent development of smart cities (e.g Al Nuaimi et al. 2015; Batty et al. 2012) and sustainable cities (e.g. Kramers et al. 2014; Bibri and Krogstie 2017), ICT solutions have been leveraged in the transition towards sustainable urban development. This has for long been promoted by systems scientists using the pragmatic framework for urban metabolism; as ICT–enabled evolution of this framework, smart urban metabolism is intended to overcome some of the current limitations of urban metabolism (Shahrokni et al. 2015), which aims to sustain the levels of sustainability of urban forms. In all, there are several critical issues that remain unresolved and underdeveloped for applied purposes with regard to the extent to which the challenge of urban sustainability can be addressed, despite the promotion of sustainable cities as a desirable goal within planning contexts.

The debate over the ultimate urban form continues, so does the evolvement of the concept of sustainable urban development as to developing more sustainable city models based on crafting new and making creative combinations of the typologies and design concepts of sustainable urban forms. Currently, such forms, in particular compact city, eco–city, and new urbanism, overlap in many aspects as to their visions, ideas, and concepts, although they entail some key differences as to planning tools (Jabareen 2006). This overlap can result in vast confusion in terms of conceptualizations, which in turn complicates the implementation of design concepts and planning tools (see Nam and Pardo 2011). Of pertinence to highlight here is that our study has a propensity to emphasize a mix of coherent, scalable, and dynamic typologies and design concepts together with relevant infrastructures and management systems. And in doing so, to look for a more comprehensive, extensible, and evolvable sustainable model of urban form—supported by advanced ICT enabled by the new wave of computing. This innovative approach has great potential to yield a more convincing and robust model of sustainable urban form. Indeed, it is important to shun looking for one–rule model among the existing ones by favoring certain typologies, design concepts (e.g. Kärrholm 2011), and smart applications (e.g. Batty et al. 2012). The rationale is that it is potentially valid to argue in terms of several pathways, possibilities, combinations, and futures (see Guy and Marvin 2000) in the case of considering matrices (see Jabareen 2006 for an example of matrix) for the evaluation of the sustainability of existing models of sustainable urban form, or for combining smart solutions pertaining to certain urban domains. Our study departs from this perspective and hence postulates that there is no one single optimal or ideal sustainable urban form but diverse alternative forms whose discussion should normally 'follow a more heuristic [or exploratory] trajectory, addressing a plurality of important issues and methods, rather than producing one–rule models, one–liners or optimal solutions' (Kärrholm 2011, p. 102). Important to note, indeed, is that existing urban forms differ as to their contribution to sustainability. In addition, as concluded by Jabareen (2006, p. 48), 'different…scholars may develop different combinations of design concepts [and typologies] to achieve sustainable development goals. They might come with different forms, where each form emphasizes different concepts.' Further and from a conceptually different angle, it is theoretically of high relevance to combine the relevant design concepts with smart methods for the purpose of substantiating their practicality with regard to their contribution to sustainability, as well as integrate these typologies with smart solutions for the purpose of increasing their contribution to sustainability, evaluating whether they contribute to sustainability, and identify their untapped potential for achieving the goals of sustainable development (see Bibri and Krogstie 2017). These suggestions should provide fertile insights into validating or rethinking the theoretical underpinnings of urban sustainability upon new evidence as to its effects in the context of sustainable urban forms. In our research endeavor, we aim to contribute to the existing work by extending and enhancing the studies being carried out in the field of sustainable cities. This can be accomplished by integrating the most sustainably productive typologies and design concepts with advanced ICT while taking scaling issues into consideration. For an overview of the scaling issues of sustainable urban forms, the reader is directed to Kärrholm (2011). The primary purpose of our scholarly endeavor is to advance urban sustainability with support of ICT of the new wave of computing given its enormous potential for improving urban operations, functions, designs, and services in terms of management and planning, as well as for providing flexibility for considering multiple spatial and temporal scales.

Towards this end, it is important to be cognizant that there should be no single off–the–shelf solution for making urban living more sustainable in a smart way, but a diversity of solutions should be available and encouraged—yet driven by a holistic approach into urban sustainability in terms of the integration of the established typologies and design concepts of sustainable urban forms, i.e. theoretically and empirically grounded and thus generally recognized and accepted urban strategies. Besides, feasible solutions must be adapted to the national or local context, and any urban development strategy must be based on the city's unique circumstances, capabilities, and ambitions. The diversity of solutions should primarily allow for informative or enlightening comparisons. The underlying premise is that since existing models of sustainable urban form have proven to contribute beneficially and differently to sustainability, a convergence on a theoretically and empirically grounded form—supported by the available ICT solutions and approaches—can be more valuable in terms of constructively guiding and directing future urban practices in terms of city functioning and planning—along the most desirable developmental path in an increasingly computerized urban society. This is what we are striving for as a primary goal of our study, that is developing a novel model of smart sustainable city of the future.

4.2.2. Urban Sustainability Frameworks: Indicators and Performance Assessment Tools

In the domain of urban sustainability, assessment frameworks are used to support decision–making in urban planning and development, as they entail methodologies and tools that sustainable cities rely on to show, evaluate, and improve their progress towards sustainability goals. There are many urban sustainability assessment frameworks in the literature. But we only cover and discuss the widely used and well–known performance measurement systems. Urban monitoring started in the early 1990s after establishing numerous (environmental) indicators to monitor sustainability of urban areas (Marsal–Llacuna et al. 2015), a few years after the widespread diffusion of the concept of sustainable development. The multiple indicators for measuring the quality of life appeared in the 2000s (Mercer 2014). Worth pointing out is that the explosion of indicators has been triggered by the multiplicity of interpretations of sustainable development and the widely varied approaches to its operationalization. However, urban sustainability indicators have been produced by environmental consultancy, sustainable capitalism, research, and green citizenship organizations (Ahvenniemi et al. 2017; McManus 2012). Accordingly, urban sustainability assessment tools have been developed top–down by expert organizations. However, a number of scholars (e.g. Berardi 2013; Robinson and Cole 2015; Turcu 2013) advocate the integration of citizen–led, participatory, and localized approaches. This is anchored in the underlying assumption that the relationships between urbanites, their activities, and the environment must be better understood in order to achieve the required level of sustainability in terms of the integration of its dimensions.

Sustainability indicators are used by public administration and political decision makers to confirm whether cities implement sustainable development strategies by enabling the assessment and monitoring of urban activities (Tanguay et al. 2010). However, Huang et al. (2009) note that they are associated with shortcomings, as they do not provide normative indications as to the direction to pursue, in addition to not reflecting systemic interactions. Furthermore, the performance assessment tools are intended for ranking sustainable cities or for allowing cities to find best practices and compare best solutions (Ahvenniemi et al. 2017). There exist diverse approaches to urban sustainability, thereby the diversity of performance assessment tools. In particular, a large number of environmental assessment tools have been developed for various urban domains. There are tools that measure the built environment, ranging from buildings to neighborhoods and districts, in addition to public transportation and services (Haapio 2012). Well–known neighborhood sustainability rating tools (Sharifi and Murayama 2013). Other assessment tools have been developed to help urban planners to assess the energy efficiency of a detailed city plan as regards to energy demand of buildings, transport systems, energy systems, and energy sources (Hedman, Sepponen and Virtanen 2014). Of importance to underscore is that existing sustainability performance assessment tools put a much stronger focus on environmental indicators (Berardi 2013; Robinson and Cole 2015; Tanguay et al. 2010) compared to social and economic indicators. For instance, the most well–known sustainable neighborhood rating schemes assign very low weight (about 3% for economy and 5% for well–being) to direct economic and social measures (Berardi 2013). In addition, existing sustainable design approaches have been criticized for solely focusing on reducing harm to the environment (Cole 2012; Reed 2007). Consequently, Robinson and Cole (2015) have called for the more integrative and holistic concept of regenerative sustainability. Besides, cities should be seen as urban ecosystems that comprise interactions between the physical, social, and ecological components (Nilon, Berkowitz and Hollweg 2003). The physical component is associated with urban morphology (urban forms, spatial configurations, integration values, etc.), a field of study that is concerned with the spatial structures, organizations, and characteristic features of cities. The spatial distribution of activities, efficient use of resources, and accessibility of different services and facilities are crucial aspects of sustainable cities in terms of urban forms, operations, functions, and services, as well as their interconnections (Bourdic, Salat and Nowacki, 2012; Salat and Bourdic 2012).

4.2.3. Intellectual Challenges

Sustainable urban forms for human settlements have been developed to meet the required level of sustainability by enabling the urban systems (built form, infrastructure, ecosystem and human services, and administration) and thus the urban domains to function in a constructive way. Seeking more convincing and robust models of these forms continues to be a significant challenge that motivate and induce scholars in different disciplines and practitioners in different professional fields to generate new ideas about, create new approaches into, and put forward new frameworks for redesigning, rearranging, and enhancing urban areas across multiple spatial scales, with the ultimate aim of achieving sustainability in terms of the integration of its dimensions. To develop a model of a high replicative capacity and seminal influence has simply been one of the most significant intellectual challenges for more than two decades. This implies that it has been difficult to translate sustainability into the built and infrastructural forms of contemporary cities, notwithstanding the importance of the topic of sustainability in urban research and planning. In addition, research, whether theoretical or empirical, tends to be scant on evaluating whether or the extent to which existing models of sustainable urban form contribute to sustainability or comparing different models according to their contribution to the goals of sustainable development. The very first endeavor in this direction was Jabareen's (2006) study, an attempt to develop a conceptual framework for assessing the sustainability of four urban forms: eco–city, compact city, new urbanism, and urban containment, and to articulate the underlying design concepts and principles. Still, although there appears to be in research on sustainable urban forms (e.g. ;Jabareen 2006; Hildebrand 1999a) and anthologies (Williams, Burton and Jenks 2000; Jenks and Dempsey 2005) a consensus on topics of relevance to urban sustainability, it is not evident which of these forms are more sustainable and environmentally sound. Indeed, a critical review of existing models of sustainable urban form as approaches addressed on different spatial scales demonstrates a lack of agreement about the most desirable urban form in terms of the contribution to sustainability (see, e.g., Harvey 2011; Tomita et al. 2003; Williams, Burton and Jenks 2000). It is not an easy task to 'judge whether or not a certain urban form is sustainable' (Kärrholm 2011, p. 98). Even in practice, many planning experts, landscape architects, and local governments are—in the quest to figure out which of the existing sustainable urban forms is the most sustainable—grappling specifically with dimensions of these forms by means of a range of urban planning and design approaches (Jabareen 2006). On the face of it, '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' (Jabareen 2006, p. 48).

Furthermore, as hinted at above (performance assessment frameworks), sustainable urban forms tend to emphasize environmental or economic goals, and fall short in considering social goals (see, e.g., Bibri and Krogstie 2016a; Jabareen 2006). For instance, in the context of compact city, social and environmental goals continue to play second fiddle while economic goals remain at the core of planning (Hofstad 2012). And in the realm of eco–city, the environmental dimension of sustainability is primarily linked to economic benefits and priorities, as the ambition of developing green and energy efficiency technologies is increasingly motivated more by economic values than by environmental gains (Bibri and Bardici 2015). In short, environmental sustainability is viewed as a source of economic development. Besides, urban planners and policymakers are still, and will continue to, face difficult decisions about how they set priorities as to, and where they stand on, promoting economic development, protecting the environment, and fostering social equity in cities (Bibri and Krogstie 2016a). The integration of sustainability dimensions is still of a loose kind at most, and is often associated with empty rhetoric, as economic aspects dominate in most instances. Nonetheless, there is an 'optimistic view that new procedures are likely to emerge and develop that strengthen the influence of social and ecological goals over urban planning and development practices'; regardless, to adopt sustainable development strategies and to reach sustainability can only 'occur through a sustained period of reflective thinking about existing societal models, accepting unavoidable changes, and confronting and resolving rather unshakable conflicts.' (Bibri and Krogstie 2016a, p. 26). In essence, the value of sustainability 'lies in the long–term goals of a socio–ecological system [human society within the biosphere] in balance: society strives to sustain the ecological system along with the economic system and social system. Hence, as a goal set far enough into the future, sustainability allows us to determine how far away we are from it and to calculate whether (and how) we will reach it.' (Bibri 2013, p. 8)

4.3. Smart Sustainable Cities
4.3.1. On the Emergence of the field

Not until very recently, smart sustainable urban development has attracted significant attention among contemporary urban scholars, planners, and policymakers. Its insertion, functioning, and evolution as a discourse and social practice is increasingly shaped and influenced by emerging ICT industry consortia, collaborative research institutes, policy networks, and 'Triple Helix of university–industry–government relations' (Etzkowitz and Leydesdorff 2000) in terms of techno–urban innovation, not least in ecologically and technological advanced nations (Bibri and Krogstie 2016a). While there is a growing interest in this flourishing interdisciplinary field of research, the academic discourse on smart sustainable urban development within the relevant literature is still scant—yet rapidly burgeoning. Indeed, very few studies (e.g. Bibri and Krogstie 2016a; Kramers et al. 2014; Kramers; Wangel and Höjer 2016; Rivera, Eriksson and Wangel 2015) exploring the subject of smart sustainable cities have been published in mainstream journals. The case is evidently different from smart cities and sustainable cities as urban development strategies, which have witnessed a proliferation of academic publications and thus varied emphases of research and a large body of practices. However, the speed at which the field of smart sustainable cities is gaining momentum and attracting attention gives a clear indication of its developmental path, flourishing nature, and future direction. In fact, this field of research comes as a natural pursuit within urban planning and development considering the unsolved and unsettled issues pertaining to existing models of sustainable city in terms of their contribution to sustainability, coupled with the deficiencies associated with the sustainability of existing approaches to smart city.

4.3.2. Research Strands

The body of work available on smart sustainable cities thus far is evolving mainly out of theoretical, analytical, and overarching perspectives pertaining to smart cities and sustainable cities. One key strand of research tends to focus on combining aspects of existing sustainable city models and smart city approaches in an attempt to overcome the aforementioned issues relating to sustainability. Murray, Minevich and Abdoullaev (2011) maintain that a systemic integration of eco–city, knowledge city, and digital city as solutions for moving towards sustainability results in a smart urban planning approach. Batagan (2011) points out that this holistic approach holds potential to address the challenge of urban sustainability. Future research endeavors in this direction are expected to provide normative prescriptions for achieving the status of smart sustainable cities as well as to develop frameworks to measure this status. ITU (2014) provides a standardized basis for developing such frameworks. Thus far, there are many frameworks that can be used to measure either the smartness or the sustainability of the cities, as discussed above. In view of that, another strand of research concerns itself with developing integrated frameworks to measure the combination of these two urban constructs in the ambit of smart sustainable cities. Work in this area remains very scant due to the fact that the research is still in its infancy. There is no comprehensive framework in the literature that can tackle the dimensions of smart sustainable cities (Al–Nasrawi, Adams and El–Zaart 2015). In relation to this, Ahvenniemi et al. (2017) have attempted to develop an understanding of the commonalities and differences between the concepts of sustainable cities and smart cities as well as the related assessment frameworks by comparing 16 existing performance measurement systems (8 related to sustainable city and 8 related to smart city) with respect to 12 application domains in total and 3 impact categories of 958 indicators altogether. They conclude that there is large gap between smart city and sustainable city assessment frameworks with respect to sustainability. This supports the aim of our study in terms of integrating the ICT solutions of smart cities with the typologies and design concepts of sustainable cities to increase the contribution to the goals of sustainable development under smart sustainable cities.

Like the fields of smart cities and sustainable cities, the emerging field of smart sustainable cities is evolving into broad streams of scholarship, in addition to the above strands of research. One stream of scholarship is concerned with the theory of smart sustainable urban development and the effects of the combination of smartness and sustainability applications in contemporary cities, i.e. the implications of the practices of urban computing, urban ICT, and applied urban science for urban sustainability. The strand of work focused on the respective applications addresses questions around the role of smart solutions in catalyzing, boosting, and maintaining sustainable urban development processes, i.e. using advanced technologies to monitor, understand, probe, assess, and plan cities to improve sustainability (e.g. Bibri and Krgsotie 2016a; Bibri and Krogstie 2016b; Höjer and Wangel 2015; Kramers et al. 2014; Kramers, Wangel and Höjer 2016; Rivera, Ericsson and Wangel 2015). Smart solutions involve constellations of instruments encompassing sensing technologies, big data analytics, context–aware computing, cloud computing, and wireless communication networks and their use within diverse urban domains (e.g. transport, mobility, energy, environment, governance, healthcare, education, and safety). However, the current state of research in the realm of smart sustainable cities—a blossoming scholarly interdisciplinary field—shows that research is still in its early stages. Indeed, topical studies have typically focused on developing definitions and working with conceptualization and discursive issues (e.g. Bibri and Krogstie 2016a; Höjer and Wangel 2015; Rivera, Eriksson and Wangel 2015) to provide a joint understanding of this new techno–urban phenomenon and to serve as a ground for further discussions on what this evolving urban development strategy and techno–urban discourse aspire and claim to deliver in terms of smart sustainable urban planning. In addition, a part of the emerging analytical strand of research attempts to test some propositions (smart–urban solutions) about what makes a city smartly more sustainable. This line of work tends to be narrowly focused. For example, a recent study carried out by Kramers et al. (2014) addresses the topic of energy efficiency, i.e. using ICT solutions to reduce household energy use in cities, from an analytical perspective. While the authors focus solely on energy use, they did acknowledge that sustainability consists of interrelated environmental, social, and economic dimensions and concerns. Rivera, Eriksson and Wangel (2015) explore the potential of ICT to contribute to urban sustainability from a practice–oriented perspective in the context of smart sustainable cities, focusing more on discursive issues.

In addition, given the fact that sustainability is an integral part of some definitions of smart city, the concept of smart city has been used interchangeably with that of smart sustainable city, leading to confusion and misunderstanding in the urban domain. Some views might contend that 'the smart city is the smart sustainable city and that the word 'sustainable' can be left out without further ado' (Höjer and Wangel 2015; p. 9). The different conclusions led to by recent studies (e.g. Kramers et al. 2013; Neirotti et al.2014) on the integration of sustainability in smart cities can be explained by the gap between the theory and practice of smart cities. In contrast to the study carried out by Kramers et al. (2013), which shows that a few of smart city concepts include explicit objectives of environmental sustainability, the study conducted by Neirotti et al. (2014) indicates that environmental sustainability is explicit through the most common types of urban application domains being 'Natural Resources and Energy' and 'Transportation and Mobility' for smart city initiatives. Nevertheless, the key insight here is that the concept of smart city and what it entails in terms of smart applications holds some potential for sustainability—if astutely leveraged in the needed transition towards sustainable urban development. In other words, the concept of smart city provides solutions and approaches that can make sustainable cities smartly sustainable—if driven by a long–term planning approach that centers on sustainability. Colldahl, Frey and Kelemen (2013) argue that the concept of smart city is a powerful approach to enabling cities to move towards sustainability.

Furthermore, a large part of research work on smart cities is currently focusing on a wide variety of technological propositions about what makes cities smart in terms of sustainability, efficiency, equity, the quality of life, or a combination of these. However, this relationship is too often, if not always, addressed separately from the rather established strategies through which sustainable urban forms can be achieved, namely density, diversity, compactness, mixed–land use, sustainable transport, ecological design, and passive solar design. Adding to this is the fact that the so–called smart technologies are sometimes used in cities without making any contribution to sustainability. For many contemporary urban scholars, theorists, and planners, these strategies are necessary to be adopted and implemented to achieve sustainability (see, e.g., Dumreicher, Levine and Yanarella 2000; Williams**,** Burton and Jenks 2000; Jabareen 2006; Kärrholm 2011)—irrespective of how intelligently other urban systems than the built form can be operated, managed, planned, and developed. ICT as an enabling and constitutive technology can indeed make substantial contributions in relation to these strategies. This involves not only catalyzing and boosting the development processes of sustainable urban forms, but also monitoring, understanding, probing, assessing, and planning these forms to advance their contribution to sustainability. Cities become smart sustainable when smart ICT is employed for making them more sustainable (Höjer and Wangel 2015). How this can, or should, be accomplished is a question of what the body of research on both sustainable cities and smart cities suggests as to what is currently of priority, urgency, timeliness, and necessity to pursue as research endeavors in order to address the most critical issues around existing models of sustainable urban form using innovative solutions offered by advanced approaches to smart city. Another way forward is simply the adoption of the cutting–edge solutions being offered by smarter cities in terms of the underlying core enabling technologies and their novel applications and services for sustainability (Bibri and Krogstie 2016a). It is argued that as data sensing, information processing, data analytics capabilities, and wireless communication solutions become deeply embedded into urban systems and urban domains and attached to everyday objects and citizens to address the challenge of sustainability, we can speak of sustainable cities getting smarter as to contributing to the goals of sustainable development more effectively and efficiently (Bibri and Krogstie 2016a). However, regardless of the type of smart solutions proposed for sustainability, it is of critical importance to ensure smart initiatives resonate with the significant themes in debates on the typologies and design concepts of sustainable urban forms. Jabareen (2006) provides a detailed account of these themes. Bibri and Krogstie (2017) propose a matrix linking these themes with the applications being offered by ICT of the new wave of computing (UbiComp, AmI, the IoT, and SenComp) in the context of sustainable cities of the future.

4.3.3. Scientific and Intellectual Challenges and Environmental Risks

Smart sustainable cities of the future are most likely to involve the majority of the scientific and environmental challenges associated with smart cities of the future and some of the challenges pertaining to existing sustainable city models, at least in the short term. In this case, they will have to address and overcome these challenges in order to adhere—as a holistic approach to urban development—to the vision of sustainability. Here we focus on the challenges in relevance to our study. In this regard, the major scientific challenges to the development of smart sustainable cities encompass the following:

- To relate sustainable urban forms in terms of their typologies, infrastructures, management systems, ecosystem services, and human services to their operation, organization, coordination, planning, and development through monitoring, analysis, evaluation, management, control, and optimization, and what these entail in terms of modeling, intelligence, simulation, decision support, and prediction. In this respect, the efforts should be directed towards demonstrating how developments in big data analytics and context–aware computing and related infrastructures (data processing platforms, cloud computing infrastructures, and middleware architectures) can be integrated so to make these forms intelligently more sustainable in the way urban planners, urban administrators, and city authorities can use new technological applications, services, and capabilities for improving sustainability and integrating its dimensions.

- To explore the idea of sustainable urban forms as techno–urban innovation labs, which entails developing intelligence functions as new notions of the way these forms operate and be managed. These intelligence functions can, by utilizing the complexity and data sciences in developing advanced simulation models and optimization methods, allow the monitoring and design of these forms with respect to the efficiency of energy systems, the improvement of transport and communication systems, the effectiveness of distribution systems, and the efficiency of public and social service delivery. These intelligence functions can take the form of centers for scientific research and innovation with the primary purpose of continuously increasing the contribution of these forms to sustainability thanks to the possibility for building dynamic models of urban forms functioning in real time from routinely sensor–based/machine generated data.

- To construct and aggregate several urban simulation models of different situations of urban life pertaining to the way different urban domains within sustainable urban forms can be integrated and collaborate, as well as to how human mobility data can be linked to the spatial organizations, transport networks, mobility and travel behavior, socio–economic network performance, environmental performance, and land use, of these forms. Also to explore and diversify the approaches to the construction and evolution of urban simulation models. This is to inform the future design of sustainable urban forms on the basis on predictive insights and forecasting capabilities. This is increasingly becoming achievable due to the recent advances in, and pervasiveness of, sensor technologies and their ability to provide information about medium– and long–term changes in the realm of real–time cities.

- To improve different aspects of physical (and virtual) mobility using ICT of the new wave of computing in terms of big data analytics and context–aware computing, in particular in relation to such typologies as density, diversity, compactness, and mixed–land use by using both sustainable as well as efficient transport. Also to enhance spatial and non–spatial accessibilities to various job opportunities, public services, social services, and facilities in the context of sustainable urban forms.

As to the intellectual challenges, the practical use of the concept of smart sustainable cities requires the development and implementation of robust assessment methods and practices (indicators/metrics and their evaluation) to ensure that these cities are in fact (intelligently) sustainable (Höjer and Wangel 2015).This involves taking a holistic approach into evaluating the effects of ICT solutions on environmental sustainability (Bibri and Krogstie 2016a). It is relevant to mention again that one of the significant challenges in the realm of sustainable cities is to develop and apply methods for identifying which kinds of solutions (combining design concepts, typologies, infrastructural systems, environment and urban management, environmental technologies, etc.) are needed, and also for evaluating the effects of these solutions in terms of their contribution to the goals of sustainable development based on a systemic perspective. Without evaluative approaches and practices, smart sustainable cities risk becoming no more than labels (see Höjer and Wangel 2015), just like some sustainable urban forms becoming fallacies (e.g. Neuman 2005)—without validated urban content or only for urban labelling (Bibri and Krogstie 2016a).

In addition, the prospect of smart sustainable cities is increasingly becoming the new reality with the massive proliferation of data sensing, data processing, pervasive computing, and wireless networking technologies across urban environments. In other words, smart sustainable cities typically rely on the fulfillment of ICT visions of the new wave of computing. Consequently, it becomes inescapable to avoid the multidimensional effects ICT has on the environment. Due to the scale of its ubiquity presence and the massiveness of its use, future ICT has a number of risks and uncertainties in relation to environmental (and social) sustainability that need to be understood when placing high expectations on and marshaling colossal resources for developing, deploying, and implementing smart sustainable cities. There exist 'intricate relationships and tradeoffs among the positive impacts, negative effects, and unintended consequences for the environment' (Bibri 2015b), flowing mostly from the design, development, use, application, and disposal of UbiComp, AmI, the IoT, and SenComp technologies throughout smart sustainable cities. As argued by Bibri and Krogstie 2016a, p. 26), 'it is difficult to estimate the potential of ICT for environmental sustainability in a…meaningful way in the ambit of smart sustainable cities, as advanced ICT solutions involve technological innovation systems embedded in much larger socio–technical systems in which a web of factors and actors other than merely scientific and technical potential come into play… ICT…own emissions are increasing due to the growing demand for its advanced applications and services being offered by UbiComp, AmI, the IoT, and SenComp… The adverse environmental effects of new technologies are multidimensional, complex, and intricate.' They include constitutive effects, rebound effects, indirect effects, direct effects, and systemic effects. For a detailed account and discussion of these effects, the reader is directed to Bibri and Krogstie (2016a). Again, it is very challenging, if not daunting, to evade the conflicts among the goals of sustainable urban development. Brown (2012) argues that sustainability science must involve the role of technology in aggravating the unsustainability of social practices (e.g. urban planning and development), just as in tackling the complex problems these practices generate. In all, unless smart sustainable cities can 'be reoriented in a more environmentally sustainable direction, as [they] can not, as currently practiced, solve the complex environmental problems placed in [their[agenda' (Bibri and Krogstie 2016a), they risk becoming fallacies in the long term. ICT solutions should in this regard be carefully implemented in conjunction with other measures as well as policy and planning instruments to yield the desired outcomes as to the environmental gains and benefits expected to result from the development and implementation of smart sustainable cities of the future. Towards this end, it is important to underscore from the perspective of smart sustainable urban development that for advanced ICT solutions to function constructively, a concerted action is required, which should be guided by a coordinating body with relevant roles and competences in order to strategically assess the implications of ICT investments in this direction (see Höjer and Wangel 2015), and thereby steer ICT innovations in ways that align with the goals of sustainable urban development towards achieving the long–term goals of urban sustainability within ecologically and technologically advanced nations (Bibri and Krogstie 2016a).

4.3.4. Key Discrepancies between Smart Cities and Sustainable Cities

Here we outline key discrepancies (a lack of compatibility) (see Table 1) between smart cities and sustainable cities as regards to enhanced levels of sustainability. This is intended to inspire or stimulate further scholarly or academic inquiry into the area of smart sustainable urban planning and development.

5. Research Opportunities and Horizons for Smart Sustainable Cities of the Future

5.1. Prospective Inquiry Avenues and Endeavors: A Research–Inspired Applied Theoretical Inquiry

It is important to underscore that the emerging field of smart sustainable cities is a fertile area of interdisciplinary scholarly inquiry, entailing clearly a wide spectrum of opportunities, horizons, and endeavors, with many intriguing questions and multifaceted phenomena awaiting scholars and practitioners in different disciplines. This is underpinned by the recognition by research community that the concept of smart sustainable city holds great potential to enable urban environments to function sustainably in a more constructive way than at present. Its main strength lies in the high influence it will have on many domains of contemporary cities and what this entails in terms of sustainability and the integration of its environmental, social, and economic dimensions. This is coupled with the unique opportunity to take stock of and harness the plethora of the lessons learned from more than two decades of research and planning devoted for seeking and implementing sustainable urban forms, and how to apply this together with the most advanced ICT solutions to the sustainability challenge of our time, which is the success of the goals of sustainable development. Therefore, it is high time to leverage the theoretical and substantive knowledge accumulated hitherto on smart sustainable urban development through recent research endeavors that can contribute to make urban living smartly more sustainable—i.e. with support of ICT of the new wave of computing in terms of what it has to offer as innovative solutions and sophisticated approaches directed for improving sustainability.

The research opportunities currently available within the field of smart sustainable urban development are vast, ranging from applied theoretical studies, to theoretical development studies, to exploratory studies (e.g. Al–Nasrawi, Adams and El–Zaart 2015; Ahvenniemi et al. (2017), to empirical studies (e.g. Kramers, Wangel and Höjer 2016; Shahrokni et al. 2015), to analytical studies (e.g. Kramers et al. 2014), and to discursive and institutional studies (e.g. Bibri and Krogstie 2016a; Rivera, Eriksson and Wangel 2015). Of these studies, research endeavors within or towards theoretical development for the purpose of application remains scant (little or no)—yet of utmost relevance and importance at this stage of research within smart sustainable cities—as it is still in its infancy. This is primarily to contribute to laying the foundations for future urban practices in terms of the smart form of sustainable development. While this can take various forms to achieve, previous urban research on sustainable urban forms (e.g. Girardet 1999; Gibbs, Longhurst and Braithwaite 1998; Jabareen 2006; Jenks, Burton and Williams 1996a, b; Nijkamp and Perrels 1994; Register 2002; Wheeler 2000; Roseland 1997; Williams, Burton and Jenks 2000) shows that seeking models of these forms, or putting forward new frameworks for the restructuring and redevelopment of urban environments across several spatial scales to achieve sustainability, was of prime focus during the inception and application of sustainable development into urban planning. This also applies, to some extent, to early research within the field of smart cities (e.g. Giffinger et al. 2007). In view of that, following this research path in the context of smart sustainable cities is deemed of high pertinence and thus more encouraged at this stage of research, or generally when it comes to the emergence of new urban development strategies. Our research pursuit is indeed in the spirit of the way sustainable cities, in particular, as complex systems have actually materialized and evolved into established models of sustainable urban form. Any research endeavor in this direction should make best use of what has been done with regard to the accumulated knowledge in the field of sustainable cities as well as in that pertaining to smart city approaches that explicitly incorporate the goals of sustainable development. Of equal importance in this respect is to attempt to take into account what has been criticized in the context of sustainable cities and smart cities in terms of deficiencies, uncertainties, fallacies, paradoxes, and misunderstandings regarding the development of smart sustainable cities of the future. Overall, it is deemed of high relevance to develop, using the relevant scales of design concepts and topologies of sustainable urban forms in conjunction with smart technologies and their novel applications, a theoretically and practically convincing model of smart sustainable city or a framework for strategic smart sustainable urban development.

5.2. Towards an Integrated Approach into Smart Sustainable Urban Form: Justifications and Beyond

In light of the above, a worthy and pertinent research endeavor to engage in is to develop an integrated approach into smart sustainable urban form that can have academic buy–in and practical relevance in relation to the future form of smart sustainable urban planning and development. The rationale for this research pursuit is manifold. To begin with, theoretical development has been notably slow in respect of sustainable city models as to their integration with smart city approaches. Moreover, there is a need for applied theoretical grounding that can provide an adequate explanation of and a strong basis for the potentially increased contribution of smart sustainable urban form to the goals of sustainable development given that the research in the field is still in its early stages, and therefore there is a need for integrated frameworks to spur the practice of the development of smart sustainable cities (or urban forms). Additionally, there has been no attempt to develop any framework for smart sustainable urban form to be used as a classification system or ranking instrument against which existing and new smart sustainable cities can be evaluated in terms of their contribution to sustainability. Even in relation to sustainable cities, although existing sustainable urban forms are conceptually diversified and strategically nuanced, theoretical foundations and lineages seem to be in practice disregarded, and distinctions among or comparisons between models are less significant, while pragmatic concerns are more prominent and tend to prevail in urban projects and initiatives (see, e.g., Jabareen 2006; Kärrholm 2011; Rapoport and Vernay 2011). In particular, common conceptual or integrative frameworks for comparing sustainable city models and planning propositions are very scant. For instance, there is a lack of theory that can assess whether and the extent to which existing models of sustainable urban form contribute to sustainability or contrast their variations based on their contribution to the goals of sustainable development, to iterate. A number of other questions has arisen from the existing body of research work on sustainable urban forms reviewed above that deserve more attention and motivate new research in the applied theoretical direction—in addition to questions involving the integration of sustainable city models and smart city approaches. One major critique of the literature on sustainable urban forms and smart cities is that it tends to be heavy on speculation and light on theoretical development and applied theoretical studies—existing design concepts and principles pertaining to these forms and emerging ICT applications for smart cities have inadequate explanatory power, especially with regard to their combination in a given city model—as well as light on empirical evidence concerning the same facet. Regardless, sustainable and smart cities tend to present ideals, and much of what they claim in the context of sustainability remains still at the level of discourse (e.g. Batty et al. 2012; Hofstad 2012; Roseland 1997). The same in fact goes for smart sustainable cities at the current stage of their conceptualization and vision (e.g. Bibri and Krogstie 2016a). Adding to this is that existing models of sustainable urban form as to the underlying design concepts and typologies tend to be static and fail to account for changes over time. Whereas a well–established fact is that cities evolve and the knowledge underlying their design and planning is perennially changing. Conceiving urban forms as 'processual outcomes of urbanization' pave the way for dynamic conception of urban planning that reverses the focus on urban forms governed by static planning tools (Neuman 2005), to iterate. Here ICT is of high significance given its symbiosis character with urbanization. This dynamic conception become even of critical importance when including ICT in the equation—because ICT develops rapidly due to the pace of innovation in computing—as to its integration with the design concepts and typologies of sustainable urban forms. Smart sustainable cities of the future need to be scalable in design and flexible in planning as to their functioning and management as a way to respond to urban growth, environmental pressures, and changes in socio–economic needs. Indeed, at the core of smart sustainable cities of the future is the conception of building and using urban dynamic and simulation models and intelligence functions that adapt to the changing and evolving urban forms and the underlying urban systems and domains as well as their evolution.

5.3. A Comprehensive List of of the Gaps in the Research within the Field of Smart Sustainable Cities

On the basis of our analysis and discussion done in the previous sections, we present here a comprehensive list of the existing gaps in the research within the field of smart sustainable cities (see Table 2). This list includes the key gaps that we aim to address in our study based on an applied theoretical approach. As for the other gaps, they constitute potential research directions. They are therefore meant to encourage scholars in the field of smart sustainable cities to pursue theoretical, applied theoretical, exploratory, analytical, empirical, discursive, and futuristic inquiries.

5.4. Major Advantages of Smart and Sustainable Cities

We now present a tabulated version of our analysis with respect to the major advantages of smart and sustainable cities (see Table 3 and 4). The purpose is to provide insights into understanding the relevance and meaningfulness of merging and harnessing the strengths of smart and sustainable cities into an integrated approach for applied purposes as to future practices in the area of smart sustainable urban planning and development. This can be accomplished by developing a model that entails smartening up existing models of sustainable urban form through integrating the most sustainably sound typologies and design concepts of these models with the most advanced solutions and approaches of smart cities in light of ICT of the new wave of computing.

6. Future Urban Planning Practices and Emerging Scientific and Technological Trends

6.1. Unprecedented Changes in Urbanism and Sustainable Urban Planning

The recent wave of smart sustainable urban planning is heralding major changes in the context of urbanism and sustainability. The research and practice in the field of smart sustainable cities tends to focus on the identification of the urban domains that are associated with sustainability dimensions (such as transport, energy, environment, mobility and accessibility, public and social services, and public safety)—on the basis of big and context data—for further analysis, interpretation, reasoning, and modeling to develop and employ urban intelligence and simulation models for strategic decision–making purposes pertaining to sustainability (Al Nuaimi et al. 2015; Batty et al. 2012; Bibri and Krogstie 2016b), among other things.This also involves how these domains interrelate and affect one another in relation to particular organized and coordinated physical arrangements and spatial organizations. In light of this, urbanism (the way of life characteristic of cities) has become as much a function of sensed, processed, analyzed, modeled, simulated, and networked urban data as it is of an organized, coordinated, and standardized physical arrangement of the city and the underlying infrastructural systems, processes, functions, and services in terms of management, planning, and development (e.g. Batty et al. 2012; Batty 2013a; Batty 2013b; Bibri and Krogstie 2016a, b; Böhlen and Frei 2009). Accordingly, the concept and development of smart sustainable cities entail thinking about and conceiving of urban environments as constellations of instruments across spatial and temporal scales that are networked in multiple ways to provide continuous data coming from urban domains, employing pervasive sensing, processing, and networking technologies, in order to monitor, understand, and analyze how cities function and can be managed so as to guide and direct their development towards sustainability. Therefore, the urban ICT enabled by the new wave of computing is drastically changing the way cities can be planned across many spatial scales and over multiple time spans, combining both short−term and long−term decision–making strategies (see Batty 2013a). One implication of this is that cities are getting smarter in their endeavors to achieve the required level of sustainability. The technical features of smart sustainable urban planning involve the application of advanced ICT as a set of scientific and technical processes to land use patterns, natural ecosystems, physical structures, spatial organizations, natural resources, infrastructural systems, socio–economic networks, and citizens' services. Recent evidence (e.g. Al Nuaimi et al. 2015; Batty et al. 2012; Bibri and Krogstie 2016a; Kramers et al. 2014; Neirotti et al. 2014; Shahrokni et al. 2015) lends itself to the argument that an amalgamation of these strands of urban planning with ICT can help create more sustainable and thus livable and attractive cities. In all, the smart approach to planning is of fundamental importance for strategic sustainable urban development, which is necessary for achieving the long–term goals of urban sustainability. Besides, the functioning, management, and organization of urban systems, processes, and activities in the field of sustainable urban planning require not only complex interdisciplinary knowledge of sustainability, but also sophisticated technologies and powerful computational and data analytics capabilities.

6.2. Evolving and Upcoming Shifts in City Approaches and Models Driven by Data Science

The evolving smart approach to sustainable urban planning and development has materialized as a result of the recent shifts in city approaches—from digital city, intelligent city, networked city, knowledge city, information city, and so on to smart cities, and from smart cities to smarter cities, namely ubiquitous city (e.g. Lee et al. 2008; Shin 2009), sentient city (e.g. Shepard 2011; Thrift 2014), ambient city (e.g. Böhlen and Frei 2009; Crang and Graham 2007), and city of an Internet of everything (e.g. Kyriazis et al. 2014). Another yet evolving shift is from smart and smarter cities to more hybrid forms of cities, such as eco−knowledge city. energy–efficient city, real−time sustainable city, sustainable ubiquitous city, and so on, which all constitute instances of smart sustainable cities. Worth noting in the event of these shifts is that ICT as technological applications of recent scientific innovations in computing has been evolving just as the underlying knowledge of how to understand technological systems and the way in which they can be applied in and transform society (in better ways) are evolving. This is predicated on the assumption that 'science–based technology develops dependently of society, in a mutual shaping process where they both are shaped concurrently and thus affect each other and evolve. In other words, science and technology…shape and influence society and vice versa.' (Bibri 2015b, p. 27). The underlying premise is that technological systems and applications as a form of scientific knowledge are embedded in the wider social context within which they arise (see Bibri and Krogstie 2016a). The social conditions as structures and processes affect scientific knowledge and activity (Joseph and Sullivan 1975), and vice versa. Social studies of science demonstrate that scientific knowledge and related system of production are shaped by the wider social context in which scientific inquiries and endeavors take place (Latour 1987; Latour and Woolgar 1986). These theoretical perspectives are of relevance to smart sustainable cities as a form of scientific knowledge, which arises from and is embedded in the wider social context. As reported by Bibri and Krogstie (2016a, p. 1), smart sustainable cities 'are mediated by and situated within ecologically and technologically advanced societies. And as urban manifestations of scientific knowledge and technological innovation, they are shaped by, and also shape, socio–cultural and politico–institutional structures.'

Furthermore, data sensing, processing, analysis, modeling, and simulation (as elements of data science) are generating radical shifts in many sciences in the information age, whether in relation to the city or other venues in modern society, such as complexity science, applied urban science, environmental science, green chemistry, sustainable development engineering, and sustainability science, as well as in the way these sciences can potentially be combined into new sciences. Speaking of the information age, the conception of smart sustainable cities epitomizes a product of a shift from a world based on energy and materials to a world increasingly grounded in information and its manipulation. In this regard, many scholars in different disciplines (e.g. Al Nuaimi et al. 2015; Batty et al. 2012; Bibri and Krogstie 2016b; Bibri and Krogstie 2017; Böhlen and Frei 2009; Kramers et al. 2014; Shahrokni et al. 2015; Shepard 2011) advocate the inclusion of ubiquitous sensing, computing, and wireless networking technologies into urban planning and development as a core feature of smart (and) sustainable cities of the future. This is marking the next wave of urban analytics, of which big data constitute a fundamental ingredient. Indeed, as citizens and other urban entities increasingly emit spatial and urban data through their use of various technologies, coupled with data science becoming a more accessible tool on a wide–city scale, more extensive data can potentially allow urban departments, city administrators, and city authorities to monitor, understand, probe, and respond to such factors as mobility, accessibility, transport, energy, public safety, healthcare, public feedback, and so on in a real–time fashion. Obviously, new urban conditions require new urban planning approaches, especially traditional urban planning approaches alone are no longer of pertinence in terms of effectively operating, managing, organizing, evaluating, and planning cities.

The traditional model of the city, which is founded on the idea of the city as being a stable or constant structure, is rapidly changing, so too are the associated planning approaches in response to the emerging shifts brought by computing and ICT, underpinned by their foundation on the complexity and data sciences: from focusing on physical and spatial development to including broader principles (e.g. sustainability) and relying on big data analytics, context information processing, intelligence functions, and simulation models, and what these entail in terms of sensing, computing, data processing, and wireless networking technologies. The basic idea is that the traditional city model can no longer handle current planning conceptions and address emerging challenges in an increasingly technologized and computerized urban world—pervaded with computer technology and dominated by computable information that leaves no physical traces and has no spatial aspects in terms of area, position, location, and shape. As supported by Batty et al. (2012), the city planning systems currently in use 'are not fit–for–purpose', and hence the shifts that need to be instigated are the kind of unprecedented paradigm changes. This entails, in the context of smart sustainable cities, the development, deployment, and coordination of ICT infrastructures, applications, and services and the underlying distributed and heterogeneous environments in terms of sensing, stream processing, cloud computing, and wireless networking on city–wide scale for a wide connectivity, accessibility, and use for relevant urban entities, as well as for collective intelligence functions and service delivery systems. Adding to this is the use of advanced techniques of big data analytics capable of handling billions of observations, transactions, and interactions for discovering new knowledge necessary for managing and planning cities and redesigning existing ones. Other paradigm changes encompass devising a new science of socio–spatial behavior and enabling existing non–digital technologies to merge and co–exist with digital technologies in an integrated fashion (Batty et al. 2012). In all, the way in which cities are understood and conceptualized has drastically changed: from being viewed as closed and static systems to being seen as complex, dynamic, adaptive, and evolving systems in terms of their behavioral patterns and internal and external interactions.

6.3. The Next Wave of City Analytics and Computing for Urban Sustainability

It is worth mentioning that the next wave of urban analytics and computing is associated with smarter cities (smart cities of the future) as well as smart sustainable cities of the future, which both rely on the fulfillment of ICT visions of the new wave of computing with the purpose of achieving smart targets and sustainability goals, respectively.

6.3.1. ICT of the New Wave of Computing: Big Data Analytics and Context–Aware Computing

Cities as complex systems, with their domains becoming more interconnected and their processes highly dynamic, rely more and more on sophisticated technologies to realize their potential for responding to the challenge of sustainability. The most prevalent and influential of these technologies are big data analytics and context–aware computing. These are rapidly gaining momentum and generating worldwide attention in the realm of smart sustainable urban development (e.g. Al Nuaimi et al. 2015; Batty et al, 2012; Bibri and Krogstie 2016b; Solanas et al. 2014). Moreover, context−aware behavior and big data capability are prerequisites for realizing the next generation of ICT and their applications (e.g. Batty et al. 2012; Bibri and Krogstie 2016b; Böhlen and Frei 2009; Coutaz et al. 2005; Schmidt 2011; Riva et al. 2008; Solanas et al. 2014; Shepard 2011; Vongsingthong and Smanchat 2014). In this regard, big data trends are mainly associated with the IoT and UbiComp technologies and context data trends with AmI and SenComp technologies, with some overlaps among both these trends as well as technologies. Worth pointing out is that the IoT is a form of UbiComp, and AmI and SenComp are two ICT visions that imply a slightly different focus in terms of the concept of context as to its elements (e.g. Bibri and Krogstie 2016a). Indeed, UbiComp and the IoT tend to deal with more physical objects and thus involve more sensors than AmI and SenComp due to the scale of their ubiquity, and hence the volume of the data generated is huge and the processes involved in handling these data are complex. Furthermore, UbiComp and the IoT involve complex sensor infrastructures and networks for the objects involved are numerous and boundless. However, in the near future, the core enabling technologies of UbiComp, the IoT, AmI, and SenComp, which involve big data analytics and context–aware computing and what these entail in terms of digital sensing technologies, cloud computing infrastructures, middleware architectures, and wireless communication networks, will be the dominant mode of monitoring, understanding, analyzing, assessing, operating, organizing, and planning smart (and) sustainable cities to improve their contribution to the goals of sustainable development. Big data analytics and context–aware computing as rapidly growing areas of ICT are becoming important to the functioning, planning and development of smart sustainable cities (Bibri and Krogstie 2016b). Therefore, the expansion of these computing approaches are increasingly stimulating the development of smart sustainable cities as urban initiatives and projects. Besides, big and context data constitute fundamental ingredients for the next wave of urban analytics and computing.

6.3.2. Opportunities and Applications of Big Data Analytics and Context–Aware Computing

The notion of big data and its application in urban analytics have attracted enormous attention among various urban scholars and practitioners over the past few years. The big data paradigm is fundamentally changing the way cities function and can be managed (e.g. Batty 2013; Bibri and Krogstie 2016b). Unquestionably, the main strength of big data lies in the high influence it will have on many facets of smart sustainable cities and their citizens (e.g. Al Nuaimi et al. 2015; Batty et al. 2012; Bibri and Krogstie 2016a, b; Khan et al. 2015; Pantelis and Aija 2013). Today, a large part of ICT investment from large technology companies like IBM, Oracle, Microsoft, SAP, and CISCO is being funneled into and directed towards how to process, analyze, manage, model, and simulate big data. In parallel, research on big data is very active in many universities and research institutions across the globe.

Context–aware computing constitutes a key component of the infrastructures of smart sustainable cities (e.g. Bibri and Krogstie 2016b; Kamberov 2015; Solanas et al. 2014) and future cities (e.g. Riva et al. 2008). Local city governments are investing in advanced ICT to provide technological infrastructures supporting AmI and UbiComp, as well as to foster respect for the environmental and social responsibility (e.g. Solanas et al. 2014). Hence, there are many opportunities for smart sustainable cities to embrace from the use of context–aware technologies due to the role they will play in several important areas, including energy, environment, education, healthcare, utility, and public safety (e.g. Batty et al. 2012; Bibri and Krogstie 2016b; Böhlen and Frei 2009; Shepard 2011; Solanas et al. 2014).

The use of big data analytics and context–aware computing as a set of sophisticated techniques, methods, and technologies offers the prospect of smart sustainable cities in which natural resources can be managed safely, sustainably, and efficiently in a smart way to improve societal and economic outcomes. Indeed, significant opportunities exist for these two technologies in relation to transforming the sustainable urban model. This is due to that the range of urban application areas that utilize big data analytics and context–aware computing in connection with sustainability is potentially huge, as these two advanced forms of ICT usher in computing and analytics in nearly all urban domains. Among these applications the following is included (e.g. Bibri and Krogstie 2016a):

- Healthcare and social support
- Learning, education, and tele–working

- Public safety and civil security
- Energy efficiency and management
- Environmental monitoring and protection
- Transport efficiency and management
- Water and waste management
- Mobility and accessibility effectiveness
- Urban infrastructure monitoring and management
- Medical and health systems
- Natural ecosystems
- Traffic management and street light control
- Strategic planning and efficient design

In other words, the key smart applications enabled by big data analytics and context–aware computing include smart transport, smart energy, smart environment, smart planning, smart design, smart grid, smart traffic, smart education, smart healthcare, and smart safety (Bibri and Krogstie 2016b). Therefore, the opportunities for the development and deployment of the innovative solutions offered by ICT of the new wave of computing are tremendous—if it can be directed towards urban sustainability and its investment be justified by environmental concerns and socio economic needs in terms of unlocking the potential and exploiting the benefits of big data analytics and context–aware computing in the realm of smart sustainable cities. As argued by Bibri and Krogstie (2016b, p. 1), 'combining big data analytics and context–aware computing could be leveraged in the advancement of urban sustainability, as their effects reinforce one another as to their efforts for transforming urban life in this direction by employing and merging data–centric and smart applications to enhance, harness, and integrate urban systems as well as facilitate collaboration and coupling among diverse urban domains.'

6.3.3. Research Gaps and Scientific Challenges

The bulk of work relating to the recent increase of research in big data analytics and context–aware computing in the area of urban planning and development is associated with scattered and small research programs and projects. And it lacks comprehensive and large–scale initiatives. Also, while these two advanced technologies cover multiple application domains (e.g. Al Nuaimi et al. 2015; Batty et al. 2012; Bibri and Krogstie 2016b), it is undeniable the disproportionate weight of a relatively small number of urban domains in setting the research agenda. In relation to big data analytics, many sustainability issues have not yet been effectively addressed, including public health, energy, environment, disaster forecasting, water resources, and biodiversity (DeRen, JianJun and Yuan 2015). In addition, there are important questions that are largely ignored concerning the link between the urban domains associated with sustainability and the typologies and design concepts of sustainable urban forms. These questions pertain to the key themes in debates on density, compactness, diversity, mixed–land use, sustainable transport, and ecological design, as well as to the ability of monitoring, probing, and planning sustainable urban forms in ways that strategically evaluate and improve their contribution to the goals of sustainable development (Bibri and Krogstie 2017). Moreover, there are issues that are barely explored to date regarding how the urban domains operating within sustainable urban forms can be integrated and coordinated to facilitate collaboration among them in terms of operations, functions, and services for advancing sustainability (see Bibri and Krogstie 2016b).

The rising demand for big data analytics and context–aware computing as disruptive technologies presents significant scientific and intellectual challenges that need to be addressed and overcome as to the design, development, and deployment of data–centric and smart applications within smart sustainable cities. These challenges are mostly computational and analytical in nature, including constraints of design science and engineering (e.g. Bibri 2015a), data management and analysis, database integration across urban domains, privacy and security, data growth and sharing, data uncertainty and incompleteness, data quality, urban intelligence functions, urban simulation models (e.g. Al Nuaimi et al. 2015; Batty et al. 2012; Bertot and Choi 2013; Demchenko et al 2013; DeRen, JianJun and Yuan 2015; Fan and Bifet 2013; Khan, Uddin and Gupta 2014; Kitchin 2014; Krogstie and Gao 2015; Malilk 2013; Mann 2012; Solanas et al. 2014; Townsend 2013), and modeling and management of contextual information in large- scale distributed pervasive applications and in open and dynamic pervasive environments (e.g. Bibri 2015a; Strimpakou et al. 2006). Adding to these technical challenges are the financial, organizational, institutional, and regulatory ones, which are associated with the use, implementation, retention, and dissemination of big data. Controversies over the application and benefit of big data analytics relate to representativeness, limited access and related divide, and ethical concerns about accessibility (Fan and Bifet 2013). Nevertheless, by advancing the existing knowledge on the available processing, analysis, and management capabilities associated with big data analytics and context–aware computing in terms of conceptions, tools, principles, paradigms, methodologies, and risks, the goal of making cities smartly more sustainable as to their systems and domains and the underlying operations, functions, services, and designs will be attainable. This entails though ensuring the current open issues stemming from those challenges are under investigation and scrutiny by the constituents of the technological innovation system of ICT of the new wave of computing, namely industry consortia, entrepreneurial companies, universities, research institutes, policy networks, and governmental agencies.

7. Conclusions

In this paper we provided a comprehensive overview of the field of smart (and) sustainable cities in terms of its underlying foundations and assumptions, state–of–the art research and development, research opportunities and horizons, emerging scientific and technological trends, and future planning practices. This work entailed exploring an extensive and broad array of literature from, and at the intersection of, different disciplinary areas. Hence, it is a means to facilitate collaboration among and between the academic disciplines of urban planning and design, sustainable development, sustainability science, and ICT for the primary purpose of generating the interactional knowledge necessary for a more integrated understanding of the topic of smart sustainable cities. This is a key contribution that supports smart urban planning and development foundational ethos of interdisciplinarity.

The results of this interdisciplinary review allowed us to establish the status of current knowledge, and highlight several avenues for research, within the area of smart sustainable urban planning and development. The key relevant concepts, theories, and discourses are identified and discussed, and their definitions are provided and elaborated on, while highlighting important issues relating to the cross–disciplinary integration underlying the topic of smart sustainable cities. The findings show that existing smart city approaches and models of sustainable urban form are associated with many issues and challenges—when it comes to their development and implementation as to the incorporation of and contribution to the fundamental goals of sustainable development, respectively. The issues revolve around shortcomings, difficulties, uncertainties, paradoxes, and fallacies in relation to existing models of sustainable urban form, in particular compact city and eco–city, and around misunderstandings, deficiencies, and discrepancies in connection with existing smart city approaches. Therefore, there are several critical questions to address or problems to investigate concerning definitional, conceptual, theoretical, analytical, evaluative, empirical, and practical aspects.These constitute research opportunities for both smart and sustainable cities, which are open for scholars and practitioners in the field to consider. The questions pertaining to our study are specifically of an applied theoretical nature, and involve how sustainable urban forms can be better monitored, understood, analyzed, assessed, and planned with support of ICT of the new wave of computing to advance their contribution to sustainability. This is anchored in the underlying assumption that emerging and future ICT as a set of enabling and constitutive technologies (and their novel applications, data analytics capabilities, and services) can make substantial contributions in this regard—not only in terms of catalyzing and boosting the sustainable development processes of sustainable urban forms, but also in terms of planning these forms in terms of their functioning, management, and development in ways that continuously evaluate and forecast their contribution to sustainability and thus strategically advance it. Currently, one of the current formidable challenges lies in the development of a robust model of smart sustainable urban form with specified and clear typological, architectural, infrastructural, operational, and functional components and their integration with advanced ICT solutions and approaches. Hence, our overall perspective on the topic is to produce a theoretically and practically convincing model of smart sustainable urban form—with a high replicative capacity—or a framework for strategic smart sustainable urban development. This is one of the many research opportunities currently available, as corroborated in this paper, that can be realized in the realm of smart sustainable cities.

We conclude that the applied theoretical inquiry into smart sustainable cities of the future is deemed of high pertinence and importance—given that the research in the field is still in its early stages, and that the subject matter draws upon contemporary and influential theories with practical applications. This entails investigating the application of a set of integrated theories, namely urban planning and design, sustainable development, sustainability science, and ICT, as a foundation for future urban practices. Specifically, the focus is on exploring the potential for ICT of the new wave of computing to provide the technological infrastructures, solutions, and approaches needed for advancing the contribution of sustainable urban forms to the goals of sustainable development based on sustainability science. This involves developing a novel model of smart sustainable city—grounded in an effective integration of emerging and future ICT with the typologies and design concepts of existing sustainable urban forms. The underlying assumption is that ICT of the new wave of computing will result in a blend of advanced solutions and methods enabled by constellations of instruments across many spatial scales linked via multiple networks for providing continuous data coming from various urban domains, which can provide a fertile environment for smartening up the way urban sustainability can be improved. The rationale is that the contribution of existing models of sustainable urban form to sustainability has, over the last two decades or so, been subject to much debate, generating a growing level of criticism that essentially questions its practicality, intellectual foundation, and added value. As we have been at pains to point out throughout this paper, the focus is on smart sustainable urban planning and development, an approach that is driven by the quest for addressing several unsolved and unexplored issues surrounding existing sustainable urban forms as to their contribution to sustainability and its evaluation, prediction, and enhancement with support of innovative solutions and sophisticated approaches enabled by emerging and future ICT.

A research plan framing the valid research aims, objectives, questions, and methodologies for the entire research endeavor will follow. But as yet our quest is to provide information relating to the background and context of our study, highlight where excess research exists, state the key problems in terms of where new research is needed, and show how the relevant gaps can be filled in the existing knowledge within the field. To elucidate more as to the gaps in question, the need for the applied theoretical inquiry in the field of smart sustainable cities, coupled with the difficulty surrounding both the evaluation of the contribution of sustainable urban forms to sustainability as well as the translation of sustainability into the built and infrastructural components of these forms provides a strong motivation for our research pursuit. Addressing these research issues is deemed of significance and timeliness. In addition, it is academically worthy to engage in a scholarly endeavor that lies at the interface of topical subjects, i.e. of immediate relevance due to their relation to current urban phenomena.

As to the value of this literature review, the findings enable researchers to focus their work on the identified real–world challenges pertaining to and the existing gaps between smart and sustainable cities as urban development strategies, and thus to contribute to the improvement of urban sustainability with support of smart ICT. Practitioners can use these findings to identify common weaknesses and potential solutions in smart sustainable urban planning and development initiatives and projects.

Lastly, we consider that this paper provides a form of grounding for further discussion to debate over the point that emerging and future ICT has disruptive, substantive, and synergetic implications, particularly on forms of urban functioning, planning, and development that are necessary for urban sustainability practices in the future. This paper also presents a basis for encouraging in–depth research on smart sustainable cities, especially applied theoretical investigations, thorough qualitative analyses, and empirical studies focused on establishing, uncovering, and substantiating the assumptions underlying the substance behind the smart strand of sustainable urban planning and development initiatives in an increasingly technologized and computerized urban society.

Competing Interests

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Authors' Contributions

SEB and JK made equally substantive intellectual contributions to the study. They have made substantial contributions to the collection and analysis of data, have been involved in drafting the manuscript and revising it critically for important intellectual content; and have given the final approval of the current version to be published.

Submitting Author's Information

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SEB's current areas of research work include smart sustainable cities, Ambient Intelligence (AmI), Ubiquitous Computing (UbiComp), Sentient Computing (SenComp), the Internet of Things (IoT), as well as how these ICT visions of pervasive computing relate to urban design and planning, urban sustainability, efficiency of urban operations and services, and the quality of life of citizens, in addition to their core enabling technologies, namely sensor technologies, data processing platforms, cloud computing infrastructures, middleware architectures, and wireless communication networks.

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

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Table 1. Discrepancies between smart and sustainable cities

Discrepancies between Smart and Sustainable Cities
• Sustainable cities emphasize design concepts and principles and overlook smart solutions, and smart cities focus on modern ICT and efficient solutions and fall short in considering, if not ignore, design aspects. • Sustainable cities strive mainly for sustainability goals and smart cities mainly for smart targets. • Sustainability goals and smartness targets are misunderstood as to their interconnection. • Smart cities need to incorporate the goals of sustainable development and sustainable cities need to smarten up as to their contribution to these goals. • Sustainable cities need to leverage their informational landscape and smart cities their physical landscape in in line with the vision of sustainability. • There is a misunderstanding of the link between the concepts of smart cities and sustainable cities. • There is a weak connection between the concept of smart cities and environmental sustainability. • Smart city assessment frameworks and concepts need to be redeveloped and redefined, respectively, in ways that incorporate the environmental indicators and theoretical constructs of sustainable cities. • Smart technologies are being used in smart cities without making any contribution to sustainability, and sustainable urban strategies are being applied without considering smart technologies.

Table 2. Existing gaps in the research within the field of smart sustainable cities

Existing Gaps in the Research within the Field of Smart Sustainable Cities
• There is a need for applied theoretical grounding for providing an explanation of and a basis for the potentially increased contribution of smart sustainable urban form to the goals of sustainable development. • There is a need for integrated models for spurring the practice of the development and deployment of smart sustainable cities. • There is no framework to be used as a classification system or ranking instrument against which smart sustainable cities can be evaluated in terms of their smart contribution to sustainability. • There is no assessment framework for measuring how smartness enhances sustainability and vice versa. • The is no theory building attempts in respect of the integration of sustainable city models and smart city approaches. • There is a paucity of research on conceptual and theoretical models for smart sustainable cities. • There is no comprehensive models for merging the informational and physical landscapes of smart sustainable cities. • There is a need for a holistic and shared model of smart sustainable city given the systematic perspective on and the universal character of sustainability. • There is no common conceptual framework for comparing the evolving models of smart sustainable city and planning propositions. • There is a need for theory for evaluating whether and the extent to which a given model of smart sustainable city contributes to sustainability. • There is a need for theory for comparing potential models of smart sustainable city according to their contribution to sustainability goals and smartness targets as an integrated approach. • There is a weak connection between the concept and development of sustainable cities and smart cities. • There is a need for approaches into applying smart ICT as a constitutive technology to further enhance the contribution of the typologies and design concepts of sustainable urban forms to sustainability. • There is need for combining the typologies and design concepts of sustainable urban forms with smart methods to evaluate their practicality with regard to their contribution to sustainability. • Sustainable cities remain inadequately scalable in design and flexible in planning without support of smart solutions in response to urban growth, environmental pressures, and changes in socio–economic needs. • There is a need for providing normative prescriptions for achieving the status of smart sustainable cities and for developing assessment frameworks for measuring and improving this status. • There is a lacuna in analytical studies for testing propositions about what makes a sustainable city smartly more sustainable. • There is a lack of conception of sustainable urban forms in terms of processual outcomes of urbanization, which is inextricably linked to smart ICT. • Sustainable cities still focus mainly on infrastructures for urban metabolism, and fall short in considering several urban domains where smart solutions can have substantial contributions in relation to sustainability.

Table 3. Major advantages of smart cities

Advantages of Smart Cities
• Smart and data–centric applications for enhancing the contribution of the typologies and design concepts of models of sustainable urban form to the goals of sustainable development. • Sophisticated data–centric methods for evaluating and substantiating the practicality of these typologies and design concepts as to their contribution to these goals. • Data–centric techniques for comparing different models of sustainable urban form as to their contribution to these goals. • Effective models for urban design scalability, urban functioning efficiency, and urban planning flexibility necessary for responding to urban growth, environmental pressures, and changes in socio–economic needs. • Advanced tools and methods for realizing a dynamic conception of models of sustainable urban form in terms of processual outcomes of urbanization. • Smart frameworks for smartening up the metabolism of models of sustainable urban form. • Smart applications for integrating and enhancing urban systems and facilitating collaboration among urban domains in the context of models of sustainable urban form. • Relating the typologies and design concepts of models of sustainable urban form to their operational functioning and planning through monitoring, analysis, management, control, and optimization. • Exploring the idea of models of sustainable urban form as techno–urban innovation labs. • Constructing and aggregating several urban simulation models of different situations of urban life. • Diversifying modeling approaches into building urban simulation models to inform the future design of models of sustainable urban form on the basis of predictive insights and forecasting capabilities. • Improving participation, equity, fairness, safety, mobility, and accessibility. • New ways of understanding and addressing urban problems. • Identification of all kinds of urban risks, uncertainties, and hazards in models of sustainable urban form.

Table 4. Major advantages of sustainable cities

Advantages of Sustainable Cities
• Theoretically and practically grounded urban strategies for achieving the required level of sustainability. • Approaches into applying the knowledge of urban sustainability and environmental technologies to the planning and design of cities. • Sustainable development strategies for fostering advancement and innovation in urban infrastructures and their operational functioning, management, and planning, as well as in natural resources management. • Established methods for maximizing energy efficiency, lessening pollution and waste levels, and improving human life quality and well–being. • Best practices of successful implementation of sustainably sound typologies and design concepts. • Advanced knowledge on models of sustainable urban form in terms of different spatial levels: regional and metropolitan levels, city level, community level, neighborhood level, and building level. • Different combinations of density, compactness, diversity, mixed–land use, sustainable transport, ecological design, and passive solar design, with different levels of performance and contribution as to sustainability. • Successful practices of ecological diversity, green technology, integrated renewable solutions, and environmental management. • Advanced frameworks for efficient metabolism. • Practices of renewable energy, zero–waste, and carbon–neutral neighborhoods and districts. • Environmental, social, institutional, and land use policy instruments for sustainably managing urban spaces.