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A scholarly backcasting approach to a novel model for smart sustainable cities of the future: strategic problem orientation

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Abstract

Sustainable cities have, since the early 1990s, been the leading global paradigm of urban planning and development thanks to the different models of sustainable urban form proposed as new frameworks for redesigning and restructuring urban places to achieve sustainability. Indeed, huge advances in some areas of sustainability knowledge and a multitude of exemplary practical initiatives have been realized, thereby raising the profile of sustainable cities worldwide. The change is still inspiring and the challenge continues to induce scholars and practitioners to enhance existing, and propose new, models. Especially, sustainable urban forms have been problematic, whether in theory or practice, so is yet knowing to what extent progress has been made towards sustainable cities. They are associated with a number of problems, issues, and challenges and thus much more needs to be done considering the very fragmented, conflicting picture that arises of change on the ground in the face of the expanding urbanization. This involves the question of how they should be monitored, understood, analyzed, planned, and even integrated so as to improve, advance, and maintain their contribution to sustainability. This brings us to the issue of sustainable cities and smart cities being extremely fragmented as landscapes and weakly connected as approaches, despite the proven role and untapped potential of advanced ICT, especially big data technology, for advancing sustainability under what is labeled 'smart sustainable cities.' Essentially, there are multiple visions of, and pathways to achieving, such cities, which depends on how they can be conceptualized. This paper details the two parts of strategic problem orientation by answering the guiding questions for Steps 1 and 2 of the futures study being conducted. This study aims to analyze, investigate, and develop a novel model for smart sustainable cities of the future using backcasting as a scholarly approach. It involves a series of papers of which this paper is the first one. We argue that a deeper understanding of the multi-faceted processes of change or the interplay between social, technological, and scientific solutions is required to achieve more sustainable cities. Visionary images of a long-term future can stimulate an accelerated movement towards achieving the long-term goals of sustainability. The proposed model is believed to be the first of its kind and thus has not been, to the best of one's knowledge, produced, nor is it being currently investigated, elsewhere.

Keywords: Smart sustainable cities, Sustainable cities, Smart cities, Compact cities, Eco-cities, Big data science and analytics, Sustainable development, Design principles and strategies, Planning practices, Backcasting, Futures study

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Introduction

Contemporary cities have a key role in strategic sustainable development; therefore, they have gained a central position in operationalizing this notion and applying this discourse. This is clearly reflected in the Sustainable Development Goal 11 (SGD 11) of the United Nations' 2030 Agenda, which entails making cities more sustainable, resilient, inclusive, and safe (United Nations 2015a). In this respect, the UN's 2030 Agenda regards information and communication technology (ICT) as a means to promote socio-economic development and protect the environment, increase resource efficiency, achieve human progress and knowledge in societies, upgrade legacy infrastructure, and retrofit industries based on sustainable design principles (United Nations 2015b). Hence, the multifaceted potential of the smart city approach as enabled by ICT has been under investigation by the United Nations (2015c) through their study on 'Big Data and the 2030 Agenda for Sustainable Development.' In particular, there is an urgent need for developing and applying data-driven innovative solutions and sophisticated approaches to overcome the challenges of sustainability and urbanization. Regardless, the world is drowning in data—and if policymakers and planners realize the potential of harnessing these data in collaboration with data scientists, computer scientists, and urban scientists, the outcome could solve major global problems. The underlying assumption is that the unfolding and soaring data deluge with its new and extensive sources hides in itself the answers to challenging analytical questions, enables the solutions to complex challenges, provides raw ingredients to build tomorrow's human engineered systems, and plays a key role in understanding urban constituents as data agents (Bibri 2019b).

New circumstances require new responses. This pertains to the spread of urbanization and the rise of ICT as important global shifts at play across the world today, and how they are drastically changing our understanding of sustainability in cities. The transformative force of urbanization and ICT, coupled with the central role that cities can play in advancing sustainability, has far-reaching implications for societies. By all indicators, the urban world will become largely technologized and computerized within just a few decades, and ICT as an enabling, integrative, and constitutive technology of the twenty-first century will accordingly be instrumental, if not determining, in addressing many of the conundrums posed, the issues raised, and the challenges presented by urbanization (Bibri 2019b). It is therefore of strategic value to start directing the use of emerging ICT into understanding and proactively mitigating the potential effects of urbanisation, with the primary aim of tackling the many wicked problems involved in urban planning, design, operational functioning, management, and governance, especially in relation to sustainability. This is another macro-shift at play across the world today. In fact, the rapid urbanization of the world pose significant and unprecedented challenges pertaining to sustainability (e.g., David 2017; Han et al. 2016; Estevez et al. 2016) due to the issues engendered by urban growth in terms of resource depletion, environmental degradation, intensive energy usage, air and water pollution, toxic waste disposal, endemic traffic congestion, ineffective decision-making processes, inefficient planning systems, ineffective management of urban infrastructures and facilities, poor housing and working conditions, public health and safety decrease, social vulnerability and inequality, and so on (Bibri 2019b). In short, the multidimensional effects of unsustainability in modern cities are most likely to exacerbate with urbanization. And urban growth will jeopardise the sustainability of cities (Neirotti et al. 2014).

Therefore, ICT has come to the fore and become of crucial importance for containing the effects of urbanization and facing the challenges of sustainability in the context of sustainable cities which are striving to improve, advance, and maintain their contribution to the goals of sustainable development. The use of advanced ICT in sustainable cities constitutes an effective approach to decoupling the health of the city and the quality of life of citizens from the energy and material consumption and concomitant environmental risks associated with urban operations, functions, services, designs, strategies, and policies. This pertains to the way such cities should be monitored, understood, analysed, and planned to improve, advance, and maintain their contribution to the goals of sustainable development using big data technology and its novel applications (Bibri 2019b). There is an increasing recognition that advanced ICT constitute a promising response to the challenges of sustainable development due to its tremendous, yet untapped, potential for tackling different socio–economic issues and environmental problems (see, e.g., Angelidou et al. 2017; Batty et al. 2012; Bibri and Krogstie 2016, 2017a; Kramers et al. 2014). Many urban development approaches emphasize the value and role of big data technologies and their novel applications as an advanced form of ICT in advancing sustainability (e.g., Al Nuaimi et al. 2015; Batty et al. 2012; Bettencourt 2014; Bibri 2018a, b, 2019a, b, d, e; Bibri and Krogstie 2017b; Pantelis and Aija 2013; Sun and Du 2017).

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

This paper details the two parts of strategic problem orientation by answering the guiding questions for Steps 1 and 2 of the futures study being conducted. This study aims to analyze, investigate, and develop a novel model for smart sustainable cities of the future using backcasting as a scholarly approach. It involves a series of papers of which this paper is the first one. We argue that a deeper understanding of the multi-faceted processes of change or the interplay between social, technological, and scientific solutions is required to achieve more sustainable cities.

The article unfolds as follows. In "The background of the futures study" section, the background of the futures study is provided. "A backcasting approach to strategic smart sustainable city planning and development" section outlines and discusses the research methodology being adopted in the futures study. "Strategic problem orientation" section details Steps 1 and 2 of the futures study. This paper ends, in "Discussion and conclusion" section, with a summary of the key findings and some reflections.

The background of the futures study

Sustainable development has, since its widespread diffusion in the early 1990s, significantly positively influenced urban planning and development. After reviving the discussion about the form of cities, it has undoubtedly inspired a whole generation of urban scholars and practitioners into a quest for the immense opportunities and fascinating possibilities that could be explored by, and the enormous benefits that could be realized from, the planning and development of sustainable urban forms. That is to say, forms for human settlements that will meet the required level of sustainability by reshaping the built environment in ways that can improve and maintain the contribution of cities to the goals of sustainable development in terms of reducing material use, lowering energy consumption, mitigating pollution, and minimizing waste, as well as in terms of improving equity, inclusion, the quality of life, and well-being (Bibri 2019b). During the 1990s, the discourse on sustainable development produced the notions of compact city and eco-city planning and development that became a hegemonic response to the challenges of sustainable development (Bibri and Krogstie 2017a, b; Jabareen 2006; Jenks and Dempsey 2005; Joss 2010, 2011).

Sustainable cities have been the leading global paradigm of urban planning and development (urbanism) (e.g., Jabareen 2006; Van Bueren et al. 2011; Wheeler and Beatley 2010; Whitehead 2003; Williams 2009) for more than three decades. Indeed, huge advances in some areas of sustainability knowledge and a multitude of exemplary practical initiatives have been realized, thereby raising the profile of sustainable cities. The subject of 'sustainable cities' remains endlessly fascinating and enticing, as there are numerous actors involved in the academic and practical aspects of the endeavor, including engineers and architects, green technologists, built and natural environment specialists, and environmental and social scientists, and, more recently, ICT experts, data scientists, and urban scientists (Bibri 2019b). However, sustainable urban forms have been problematic, whether in theory or practice, so is yet knowing to what extent progress has been made towards sustainable cities. Such forms are associated with a number of problems, issues, and challenges and thus much more needs to be done considering the very fragmented, conflicting picture that arises of change on the ground in the face of the expanding urbanization and the scarcity of resources. Current deficiencies, inadequacies, difficulties, fallacies, and uncertainties concern the planning, design, development, and governance of compact cities and eco-cities in the context of sustainability (e.g., Bibri and Krogstie 2017a, b; Dempsey and Jenks 2010; De Roo 2000; Jabareen 2006; Neuman 2005; Williams 2009). This involves the question of how sustainable urban forms should be monitored, understood, and analyzed so as to improve, advance, and maintain their contribution to sustainability. The underlying argument is that more innovative solutions and sophisticated approaches are needed to overcome the kind of wicked problems, unsettled issues, and complex challenges pertaining to sustainable urban forms in terms of their processes and practices. This bring us to the issue of sustainable cities and smart cities being extremely fragmented as landscapes and weakly connected as approaches (e.g., Angelidou et al. 2017; Bibri 2018a, 2019b; Bibri and Krogstie 2017a; Bifulco et al. 2016; Kramers et al. 2014), despite the proven role and the untapped potential of advanced ICT for advancing sustainability under what is labeled 'smart sustainable cities.' (e.g., Bibri 2018a, b; Bibri and Krogstie 2017b;

Kramers et al. 2014) In particular, tremendous opportunities are available for utilizing big data technologies and their novel applications in sustainable cities to improve, advance, and maintain their contribution to the goals of sustainable development.

In the meantime, smart cities are increasingly connecting the ICT infrastructure, the physical infrastructure, the social infrastructure, and the economic infrastructure to leverage their collective intelligence, thereby striving to render themselves more sustainable, efficient, functional, resilient, livable, and equitable. It follows that smart cities of the future seek to solve a fundamental conundrum of cities-ensure sustainable socio-economic development, equity, and enhanced quality of life at the same time as reducing costs and increasing resource efficiency and environment and infrastructure resilience. This is increasingly enabled by utilizing a fast-flowing torrent of urban data and the rapidly evolving data analytics technologies; algorithmic planning and governance; and responsive, networked urban systems. In particular, the generation of colossal amounts of urban data and the development of sophisticated data analytics for understanding, monitoring, probing, regulating, and planning the city are the most significant aspects of smart cities that are being embraced by sustainable cities to improve, advance, and maintain their contribution to the goals of sustainable development (e.g., Bibri 2018b, 2019b; Bibri and Krogstie 2017b, 2018). For supra–national states, national governments, and city officials, smart cities offer the enticing potential of environmental and socio–economic development, and the renewal of urban centers as hubs of innovation and research (e.g., Batty et al. 2012; Bibri 2019d; Kitchin 2014; Kourtit et al. 2012; Townsend 2013). While there are several main characteristics of smart cities as evidenced by industry and government literature (e.g., Hollands 2018; Kitchin 2014), the one that this futures study, and thus this paper, is concerned with is environmental, economic, and social sustainability. Indeed, there has recently been much enthusiasm in the domain of smart sustainable/sustainable smart urbanism about the immense possibilities and fascinating opportunities created by the data deluge and its extensive sources with regard to optimizing and enhancing existing urban practices and processes in line with the goals of sustainable development. This results from thinking about and understanding sustainability and urbanization and their relationships in a data–analytic fashion for the purpose of generating and applying knowledge–driven, fact–based, strategic decisions (Bibri and Krogstie 2018) in relation to such urban domains as transport, traffic, mobility, energy, environment, buildings, infrastructure, healthcare, public safety, design and planning, governance, and science. See Bibri (2019d) for a detailed list and descriptive account of big data applications for multiple urban systems and domains.

In light of the above, recent research endeavors have started to focus on smartening up sustainable cities through enhancing and optimizing their operational functioning, planning, design, development, and governance in line with the long-term vision of sustainability under what is labeled 'smart sustainable cities' (e.g., Bettencourt 2014; Bibri 2018a, b, Bibri 2019b; Bibri and Krogstie 2017a, b; Kramers et al. 2014; Shahrokni et al. 2015). This wave of research revolves particularly around amalgamating the landscapes of, and the approaches to, sustainable cities and smart cities in various ways in the hopes of reaching the required level of sustainability and improving the living standard of citizens (Bibri 2019b). It is generally concerned with addressing a large number and variety of issues related to sustainable cities and smart cities. Accordingly, numerous research opportunities are available and can be realized in the context of smart sustainable cities. Especially, this integrated approach tends to take several forms in terms of combining the strengths of sustainable cities and smart cities based on how the idea of smart sustainable cities can be conceptualized and operationalized. Indeed, several topical studies (e.g., Angelidou et al. 2017; Bibri 2018b, 2019b; Bibri and Krogstie 2017b; Kramers et al. 2014, 2016; Rivera et al. 2015; Shahrokni et al. 2015; Yigitcanlar and Lee 2013) have addressed the combination of the sustainable city and smart city approaches from a variety of perspectives. In addition, there is a host of opportunities yet to explore towards new approaches to smart sustainable urban planning and development to mitigate or overcome the extreme fragmentation of and weak connection between the landscapes and approaches of sustainable cities and smart cities, respectively. The focus in this futures study, and thus this paper, is on integrating the design concepts and planning practices of sustainable urban forms, namely compact cities and eco-cities, with big data technologies and their novel applications being offered by smart cities of the future, specifically data-driven cities.

Smart sustainable cities as an integrated and holistic approach to urbanism represent an instance of sustainable urban planning and development, a strategic approach to achieving the long-term goals of urban sustainability—with support of advanced technologies and their novel applications. Accordingly, achieving the status of smart sustainable cities epitomizes an instance of urban sustainability. This notion refers to a desired (normative) state in which a city strives to retain a balance of the socio-ecological systems through adopting and executing sustainable development strategies as a desired (normative) trajectory (Bibri and Krogstie 2019). This balance entails enhancing the physical, environmental, social, and economic systems of the city in line with sustainability over the long run-given their interdependence, synergy, and equal importance. This long-term strategic goal requires, as noted by Bibri (2018a, p. 601), 'fostering linkages between scientific research, technological innovations, institutional practices, and policy design and planning in relevance to sustainability. It also requires a long-term vision, a trans-disciplinary approach, and a system-oriented perspective on addressing environmental, economic, social, and physical issues.' All these requirements are at the core of backcasting as a scholarly approach to futures studies. This approach facilitates and contributes to the development, implementation, evaluation, and improvement of models for smart sustainable cities, with a particular focus on practical interventions for integrating and improving urban systems and coordinating and coupling urban domains using cutting-edge technologies in relevance to sustainability. One of the most appealing strands of research in the domain of smart sustainable urbanism is that which is concerned with futures studies. The relevance and rationale behind futures research approach is linked to the strategic planning and development associated with long-term sustainability endeavors, initiatives, or solutions. And backcasting is well suited to any multifaceted kind of planning and development process (e.g., Holmberg and Robèrt 2000), as well as to dealing with urban sustainability problems and challenges (e.g., Bibri 2019b; Carlsson-Kanyama et al. 2003; Dreborg 1996; Miola 2008; Phdungsilp 2011).

A backcasting approach to strategic smart sustainable city planning and development

As a special kind of scenario methodology, backcasting is applied here to build a future model for smart sustainable cities as a planning tool for facilitating urban sustainability. Backcasting scenarios are used to explore future uncertainties, create opportunities, build capabilities, and improve decision-making processes. Their primary aim is to discover alternative pathways through which a desirable future can be reached. Following Rotmans et al. (2000) taxonomy, scenarios can be classified into different categories, including projective and prospective scenarios, qualitative and quantitative scenarios, participatory and expert scenarios, and descriptive and normative scenarios. This futures study is concerned with a normative scenario, which takes values and interests (sustainability and big data technology) into account and involves reasoning from specific long-term goals that have to be achieved.

In general, the backcasting approach is applicable in futures studies dealing with the fundamental question of backcasting, which involves the kind of actions that must be taken to achieve a long-term goal. In this context, if we want to attain a smart sustainable city, what actions must be taken to get there? Here backcasting means to look at the current situation from a future perspective. As an analytical and deliberative process (Fig. 1), backcasting entails articulating an end vision and then developing a pathway to get from the present to that end point. In more detail, backcasting scenario is constructed from the distant future towards the present by defining a desirable future and then moving step-by-step backwards towards the present to identify the strategic steps that need to be taken to attain that specified future. This involves identifying the stumbling blocks on the way and the key stakeholders that should be involved to drive change, as well as developing and assessing the policy pathway in terms of planning practices and development strategies necessary to achieve the future outcome. The use of backcasting in futures studies assumes a vision of an evolutionary process of policy with a time frame of a generation or so, which is a basic principle to allow the policy actions to pursue the path towards, and potentially achieve, a sustainable future. Moreover, in urban sustainability, planning is about figuring out the 'next steps' which are quite literally the next concrete actions to undertake. Next steps are usually based on reacting to present circumstances, creativity, intuition, and common sense, but also (conceivably) are still aligned with the future vision and direction. Therefore, researchers in backcasting should not get obsessed with the next steps without considering how aligned they are with what they ultimately aim to achieve.

Figure 1 illustrates the backcasting process in which the future desired conditions are envisioned and steps are then defined to attain those conditions. In this regard,

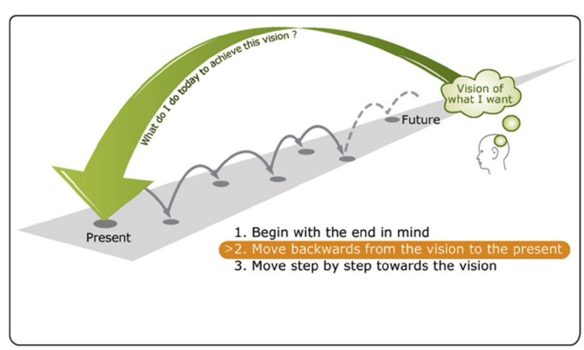

Fig. 1 The backcasting process from the Natural Step (source: Holmberg (1998))

envisioning the smart sustainable city as a future vision has a normative side: what future is desired? Backcasting this preferred vision has an analytical side: how can this desirable future be attained? Backcasting is about analyzing possible ways of attaining certain futures as well as their feasibility and potential (Quist et al. 2006). Specifically, in the quest for the answer to how to reach specified outcomes in the future, backcasting involves finding ways of linking goals that may lie far ahead in the future to a set of steps to be taken now and designed to achieve that end, and also facilitates discovery (Dreborg 1996).

Backcasting is viewed as a natural step in operationalising sustainable development (Holmberg and Robèrt 2000) within different societal spheres. In terms of its practical application, backcasting is increasingly used in futures studies in the fields related to sustainable urban planning as a formal element of future strategic initiatives. It is the most applied approach in futures studies when it comes to sustainability problems and the identification and exploration of their solutions. This involves a wide variety of areas, including strategic city planning (e.g., Phdungsilp 2011), sustainable city design (Carlsson-Kanyama et al. 2003). transportation and mobility (Banister et al. 2000), sustainable transportation systems (Akerman and Höjer 2006; Höjer 2000; Roth and Kaberger 2002), sustainable technologies and sustainable system innovation (Weaver et al. 2000), sustainable household (Green and Vergragt 2002; Quist et al. 2001), and sustainable transformation of organisations (Holmberg 1998). Backcasting studies must reflect solutions to a specified social problem in the broader sense (Dreborg 1996). Bibri (2018d) concludes that backcasting approach is found to be well-suited for long-term urban sustainability problems and solutions due to its normative, goal-oriented, and problem-solving character. Generally, as argued by Dreborg (1996), backcasting is particularly useful when:

- The problem to be studied is complex and there is a need for major change.
- The dominant trends are part of the problem.
- The problem to a great extent is a matter of externalities.
- The scope is wide enough and time horizon is long enough to leave considerable room for deliberate and different choices and directions of development.

Bibri (2018d) has recently conducted a comprehensive study on futures studies and related approaches. Its main focus is on backcasting as a scholarly approach to strategic smart sustainable city development. Its main objectives are to review the existing backcasting methodologies and to discuss the relevance of their use in terms of their steps and guiding questions for analyzing, investigating, and developing smart sustainable cities, as well as to synthesize a backcasting approach based on a number of notable future studies. Later, Bibri (2019b) adapted the approach, i.e., made minor changes so as to improve and clarify it in accordance with the overall aim of this futures study as well as the specificity of the proposed model. Indeed, a commonly held view is that the researchers' worldview and purpose remain the most important criteria for determining how futures studies can be developed and conducted in terms of the details concerning the questions guiding the steps involved in a particular backcasting approach. This helps to identify and implement strategic decisions associated with urban sustainability. However, the outcome of the adapted synthesized approach is illustrated in Table 1. Fundamentally, a backcasting study involves four steps (Höjer and Mattsson 2000), namely:

1. The setting of a few long-term targets.
2. The evaluation of each target against the current situation, prevailing trends, and expected developments.
3. The generation of images of the future that fulfill the targets.
4. The analysis of images of the future in terms of feasibility, potential, and path towards images of the future (Akerman and Höjer 2006).

The key assumptions of the applied backcasting approach encompasses the following:

- Efficient land use and conservation of green areas.
- Safeguarding biodiversity and ecosystem.
- Efficient utilization of resources.
- Decreasing resources usage and emissions.
- Integrating green and energy efficiency technologies.
- Mitigating environmental impacts (pollution and waste).
- Economic development and the quality of life.
- Social justice.
- Goal-oriented, design-oriented, and research-oriented.
- Policy-oriented and system-oriented.
- Time horizon of 25 years.
- Co-evolution of technology and society.

Strategic problem orientation

Part 1: On the futures study

This part of strategic problem orientation is concerned with setting up the direction of the model for smart sustainable cities of the future as a socio-technical system and an urbanism approach from the perspective of

Table 1 The guiding questions for each step in the backcasting study Source: Bibri (2019b)

Questions for backcasting steps	Methods
Step 1: Detail strategic problem orientation (Part 1) 1. What is the socio-technical system to be studied? 2. What are the aim, purpose, and objectives of the futures study in relation to this system? 3. What are the long-term targets declared by the goal-oriented backcasting approach? 4. What are the goals of sustainability these targets are translated to for scenario analysis?	Study design and problem formulation
Step 2: Detail strategic problem orientation (Part 2) 1. What are the key trends and expected developments related to the socio-technical system to be studied? 2. What are the major problems, issues, and challenges of sustainability and the underlying causes—the current situation? 3. How is the problem defined and what are the possible problem perceptions?	Trend analysis and problem analysis
Step 3: Generate a sustainable future vision 1. What are the demands (terms of reference) for the future vision? 2. How does the future sustainable socio-technical system and need fulfillment look like? 3. How is the future vision different from the existing socio-technical systems? 4. What is the rationale for developing the future vision? 5. Which sustainability problems, issues, and challenges have been solved or mitigated by meeting the stated objectives and thus achieving the specified targets and goals? 6. Which advanced technologies and their novel applications have been used in the future vision? 7. How can the future vision be made more sustainable and attractive?	Creativity method
Step 4: Conduct empirical research 1. What category of case studies is most relevant to the future vision? 2. How many case studies are to be conducted and what kind of phenomena do they intend to illuminate? 3. What is the rationale for the methodological approach adopted? 4. To what extent can this empirical research generate new ideas and serve to illustrate the theories underlying the future vision and to underpin its potential and practicality?	Case study method
Step 5: Specify and merge the components of the socio-technical system to be developed 1. What specific design concepts, planning practices, and technology elements are necessary? 2. What kind of urban centers and labs are necessary? 3. What spatial dimensions and scale stabilizations should be considered? 4. How can all of the ingredients be integrated into a model for strategic smart sustainable city planning and development?	Creativity method
Step 6: Perform backcasting backward-looking analysis 1. What urban and technological changes are necessary for achieving the future vision? 2. What structural, institutional, and regulatory changes are necessary? 3. How have the necessary changes been realized and what stakeholders are necessary? 4. What are the opportunities, potentials, benefits, and other effects of the future vision?	Backcasting analysis

integrating sustainability and technology and harnessing their clear synergy in advancing sustainability. Accordingly, we determine the aim, purpose, and objectives, as well as specify sustainability targets and goals. The long-term targets are to be translated into the goals of sustainability for scenario analysis.

Aim

This futures study aims to analyze, investigate, and develop a novel model for smart sustainable cities of the future using backcasting as a scholarly methodology. In doing so, it endeavors to integrate the physical landscape of sustainable cities with the informational landscape of smart cities as well as the two approaches to urban planning and development at the technical and policy levels in the context of sustainability. In more detail, it approaches this new integrated approach to urbanism from the perspective of combining the design concepts and planning practices of both the compact city and the eco-city, and then amalgamating the resulting outcome with the data-driven city in terms of the associated innovative solutions and sophisticated approaches pertaining to big data technologies and their novel applications for sustainability. Worth noting is that such approach, which is one among others that have been proposed in the field of smart sustainable cities and are being investigated further and hence not implemented yet, focuses on the core elements of urban sustainability, namely planning, design, and technology.

Purpose

As a research endeavor in its nature, this futures study intends to compile, transform, enhance, and disseminate knowledge of the smart sustainable city of the future. Its emphasis in this regard is on the untapped potential, unexploited benefits, unexplored opportunities, transformational effects, profound impacts, possible pathways, and future scenarios enabled by the emerging paradigm of big data science and analytics and the underpinning technologies with regard to sustainability. It also intends to, in general, develop the form of knowledge that can be used to guide sustainability transitions in an increasingly technologized, computerized, and urbanized world, as well as to, in particular, improve, advance, and maintain the contribution of sustainable cities to the goals of sustainable development with support of big data technologies and their novel applications as advanced forms of ICT. Worth noting is that the proposed model for smart sustainable cities is a result of the concept of urban sustainability as clarified, advocated, and established by many scholars, academics, and practitioners in the field, demonstrated in numerous real-world cities from across the globe, and, more importantly, evidenced by combining several cities from ecologically advanced nations in terms of planning practices and development strategies. According to several rankings, Sweden, Norway, Finland, Germany, and the Netherlands have the highest level of sustainable development practices (Dryzek 2005; Hofstad 2012).

Objectives

The objectives denote defining a set of specific actions for achieving the aim of the futures study. They include the following:

- Examining the planning practices and development strategies of both the compact city and eco-city to identify their preferred measures, as well as to determine the extent to which these measures produce the expected environmental, economic, and social benefits of sustainability.
- Integrating the most theoretically informed, practically successful, and widely adopted design concepts and planning practices of the compact city and the eco-city, predicated on the assumption that the former has a form and the latter is amorphous (formless).
- Compiling multiple pathways to achieving sustainable cities, and distilling the most important aspects of those being currently pursued to further inform the integration of the compact city and the eco-city based on the most advocated strategies of sustainable urban forms.
- Examining the up-to-date big data technologies and their novel applications pertaining to sustainability as associated with the data-driven city as an instance of smart cities of the future.
- Amalgamating the integrative model of the compact city and the eco-city with the data-driven city by connecting the eco-compact city in terms of policies, strategies, designs, spatial organizations, and scale stabilizations to its operational functioning and planning through control, automation, management, and optimization in the form of urban intelligence functions. This process requires digital instrumentation, urban operating system, cloud computing infrastructure, and big data ecosystem, as well as control rooms, management systems, and urban intelligence labs and centers (see Bibri 2019d for the anatomy of the data-driven smart sustainable city).

Sustainability targets and goals

Long-term targets

Here we identify the set of measures or indicators of the progress that is needed to get to the specified goals and thus realize the future vision or nearer to it in time. These measures include the following:

- High density and adequate diversity.
- Mixed land-use and social mix.
- Compactness.
- Sustainable transportation.
- Green and natural areas and biodiversity.
- Energy systems based on renewable resources, energy efficiency technologies, and integrated renewable solutions.
- Passive solar design and greening.
- Environmentally sound policies.
- Digital instrumentation, datafication, and computerization of the built environment based on cutting-edge big data technologies.
- Urban operations centers, strategic planning and policy offices, research centers, and innovation and living labs dedicated to advancing different areas of sustainability knowledge and its practice.

Specified goals

The model for smart sustainable cities of the future being predominantly based on the most prevailing, advocated, and successful models of sustainable urban form and supported with big data technologies and their novel applications as the most advanced solutions and approaches being offered by data-driven smart cities will ultimately result in numerous sustainability benefits, the most prominent among them are (e.g., Bibri 2019b; Bibri and Krogstie 2017b; Burton 2002; Dempsey 2010; Hofstad 2012; Jabareen 2006; Jenks and Dempsey 2005; Jenks and Jones 2010; Joss 2011; Joss, Cowley and Tomozeiu 2013; Rapoport and Vernay 2011):

- Decreased energy and material use.
- Reduced pollution.
- Minimized waste.
- Preserved open spaces and ecosystems.
- Reduced automobile use/car dependency.

- Effective mobility and accessibility.
- Enhanced quality of life and well-being.
- Improved equity and social justice.
- Community-oriented and livable human environments.
- Economic development and viability.

Part 2: (a) key prevailing trends and expected development

In this part of strategic problem orientation, the relevance of describing the broader context within which the analysis will take place lies in defining the different components that could act as direct inputs to the scenario analysis (Step 6).

Trend analysis: conceptual definition and analytical approach

The term 'trend' can be used to describe a pattern of change over time in some phenomena of importance and relevance to the observer. In the context of this paper, a trend comes in several forms, including global shifts, intellectual discourses, academic discourses, computing paradigms, scientific paradigms, and technological innovations. This paper is also concerned with the way these forms of trends intertwine with, affect, and inform one another in relevance to the phenomenon of smart sustainable cities.

The trend analysis as to the way it is meant to be conducted in this paper entails identifying the key forms of trends at play in the world today, and then performing an analysis to understand their nature, meaning, as well as their implications in relevance to the development of the novel model for smart sustainable cities of the future. In this case, the way forward is to look at a number of studies previously done on the diverse topics related to smart cities and sustainable cities to identify a set of pertinent, intertwined patterns of change of various kinds pertaining to these phenomena and their integration, and then to envision certain developments. One form of this envisioning in the context of this paper could be approached from the perspective on the synergy and complementarity of the respective forms of trends-of which the outcome is the development of multiple visions of smart sustainable cities as new approaches to urbanism, as well as how this phenomenon will evolve and the extent to which it will spread in the years ahead. This also involves other expected developments than smart sustainable cities and the continuation of this paradigm of urban planning and development in the future.

In addition, the trend analysis in this context requires probing what is causing the identified forms of trends to emerge, whether the causes will continue in that direction, what other external forces may affect the trends, whether they are part of rather larger societal shifts with far-reaching and long-term implications, and if there are some limitations and challenges associated with the trends.

Sustainable cities

Sustainable cities have been the leading global paradigm of urban planning and development (urbanism) (e.g., Jabareen 2006; Van Bueren et al. 2011; Wheeler and Beatley 2010; Whitehead 2003; Williams 2009) for more than three decades. In the early 1990s, the discourse on sustainable development produced the concept of sustainable cities that became a hegemonic response to the challenges of sustainability. In other words, the notion of sustainable development has been applied to, or adopted within, urban planning ever since to enable cities to move towards sustainability. In parallel, the research on and the development of sustainable cities (e.g., Girardet 2008; Williams 2009) have gained traction and prevalence worldwide, spanning a wide variety of urban domains in relation to the environmental, social, and economic dimensions of sustainability. In view of that, they have been supported and embraced by governments, policymakers, research institutions, universities, and industries (especially green and energy efficiency technologies) across the globe. The usefulness and relevance of the findings produced by the research in the field of urban sustainability and sustainable urban development has led sustainable cities as a drastic urban transformation to figure in many documents and agenda of policymakers of influential weight, such as the United Nations (UN), the European Union (EU), and the Organization for Economic Co-operation and Development (OECD). Also, such transformation has been provided as political statements and argumentations by many governments and organizations. In a nutshell, urban politics and policy around the world are infused with the language of sustainability. The whole point is that the subject of 'sustainable cities' remains endlessly fascinating and enticing, as there are numerous actors involved in the academic and practical aspects of the endeavor, including engineers and architects, green technologists, built and natural environment specialists, and environmental and social scientists, and, more recently, ICT experts, data scientists, and urban scientists (Bibri 2019b). All these actors are undertaking research and developing strategies to tackle the challenging elements of sustainable urbanism, adding to the work of policymakers and political decision-makers in terms of formulating and implementing regulatory policies and devising and applying political mechanisms and governance arrangements to promote and spur innovation and monitor and maintain progress in sustainable cities.

There are different instances of the sustainable city as an umbrella concept. These instances have been identified as models of sustainable urban forms, including compact city, eco-city, sustainable urbanism, green urbanism, new urbanism, and urban containment (Jabareen 2006). Of these, the compact city and the eco-city are advocated more sustainable and environmentally sound models. Following the advocacy and recommendation of several international policymakers, many state and local governments in varying contexts around the world have promoted both compact city and eco-city developments for what these models entail that is indispensable for sustainable urban futures (e.g., Bibri and Krogstie 2017b; Commission of European Communities 1990; Hofstad 2012; Jabareen 2006; Rapoport and Vernay 2011; van Bueren et al. 2011). However, according to Jabareen (2006), the compact city and the eco-city as the most prevalent models of sustainable urban form entail overlaps among them in their concepts, ideas, and visions: the compact city emphasizes density, compactness, diversity, and mixed-land use, whereas the eco-city focuses on renewable resources, passive solar design, ecological and cultural diversity, urban greening, and environmental management and other environmentally sound policies. In addition to land use patterns and design features, the compact city emphasizes sustainable transportation (e.g., transit-rich interconnected nodes), environmental and urban management systems (Handy 1996; Williams et al. 2000), energy-efficient buildings, closeness to local squares, more space for pedestrians, and green areas (Phdungsilp 2011). In view of that, using a thematic analysis approach, Jabareen (2006) ranks the compact city as more sustainable than the eco-city from a conceptual perspective: a matrix of sustainable urban forms for assessing the level of their sustainability performance based on the underlying topologies and design concepts.

Smart cities

In recent years, the smart city as a phenomenon has drawn increased attention and gained traction among universities, research institutes, governments, policymakers, businesses, industries, consultancies, and international organizations across the globe. The concept of the smart city became widespread during the mid 1990s due to the rise of ICT as a global shift. In recent years, it has become associated with urbanization as another global shift given the synergy between them, which are strongly at play across the world today. On this note, Townsend (2013) portrays urban growth and ICT development as a form of symbiosis. This entails an interaction that is of advantage to, or a mutually beneficial relationship between, both ICT and urbanization. One way of looking at this form of tie-in is that urbanization can open entirely new windows of opportunity, or simply provide a fertile environment, for cities to act as vibrant hubs of technological innovations in a bid to solve a wide variety of environmental, social, and economic problems and challenges, thereby containing the potential negative effects of urbanization. Further to the point, however, according to a recent review conducted by Bibri and Krogstie (2017a), the roots of the smart city concept date back to the 1960s under what is labeled the 'cybernetically planned cities', and then in urban planning and development proposals associated with networked or wired cities since the 1980s. In this respect, the common faces that emerged before, or in parallel with, the adoption of the concept of the smart city in urban planning and development around the mid 1990s include: networked cities, wired cities, cyber cities, digital cities, virtual cities, intelligent cities, knowledge cities, and cyber-physical cities, among other nomenclatures. For example, digital cities tend to focus on the hard infrastructure whereas intelligent cities on the way such infrastructure is used (Batty 1989, 1990, 1997). Moreover, several views claim that the concept of the smart city was introduced in 1994 (Dameri and Cocchia 2013), and that it is only until 2010 that the number of publications and scientific writings on the topic increased considerably, after the emergence of smart city projects as supported by the European Union (Jucevicius et al. 2014). As echoed by Neirotti et al. (2014), the smart city concept's origin can be traced back to the smart growth movement during the 1990s. Yet, it is not until recently that this movement led this concept to be adopted within urban planning and development (Batty et al. 2012).

In the early conceptualization of the concept, the smart city was mostly associated with the efficiency of technological solutions with respect to the operational functioning, management, and planning pertaining to energy, transport, physical infrastructure, distribution and communication networks, economic development, service delivery, and so forth. Smart growth implies the ability of achieving greater efficiencies through coordinating the forces that lead to policy-free growth: transportation, land use speculation, resource conservation, and economic development, rather than letting the market dictate the way cities grow (Batty et al. 2012). At present, however, many cities across the globe compete to be smart cities in the hopes of reaping the efficiency benefits economically, socially, or environmentally by taking advantage from the opportunities made possible by big data computing and its wider application across urban domains. It is also in this context that it has increasingly become attainable to achieve the required level of sustainability, resilience, equity, and the quality of life, in addition to ensuring higher levels of transparency and openness and hence democratic and participatory governance, citizenry participation, and social inclusion. Achieving all these benefits require sophisticated approaches, advanced technologies and their novel applications and services, resources, financial capabilities, regulatory policies, and strategic institutional frameworks, supported by an active involvement of citizens, institutions, and organizations as city constituents. Worth noting is that the growing interest in building smart cities based on big data technology is increasingly driven by the needs for addressing the challenges of sustainability and containing the effects of urbanization.

Smart sustainable cities

The concept of smart sustainable cities has emerged as a result of three important global shifts at play across the world, namely the rise of ICT, the diffusion of sustainability, and the spread of urbanization (e.g., Bibri 2018a, b, c, 2019b). As echoed by Höjer and Wangel (2015), the interlinked development of sustainability, urbanization, and ICT has recently converged under what is labelled 'smart sustainable cities.' Accordingly, smart sustainable cities are a new techno-urban phenomenon that materialized and became widespread around the mid-2010s (e.g., Ahvenniemi et al. 2017; Al-Nasrawi et al. 2015; Bibri 2018a, b; Bibri and Krogstie 2016, 2017a, c; Höjer and Wangel 2015; ITU 2014; Kramers et al. 2014; Kramers, Wangel and Höjer 2016; UNECE 2015b). As an integrated framework and holistic urban development approach, they amalgamate the strengths of sustainable cities in terms of the design concepts and planning practices of sustainable urban forms and those of smart cities in terms of the innovative solutions and sophisticated approaches primarily developed for sustainability and mainly offered by big data technology (Bibri 2018a, 2019b; Bibri and Krogstie 2017b, c). The whole idea revolves around leveraging the convergence, ubiquity, advance, and potential of ICT of pervasive computing and its prerequisite enabling technologies, especially big data analytics, in the transition towards the needed sustainable development and sustainability advancement in an increasingly urbanized world. Therefore, smart sustainable cities are increasingly gaining traction and prevalence worldwide as a response to the imminent challenges of sustainability and urbanization. They are moreover being embraced as an academic pursuit, societal strategy, and, thus, evolving into a scholarly and realist enterprise around the world, not least within ecologically advanced nations. In a nutshell, the concept and development of smart sustainable cities are gaining increased attention worldwide among research institutes, universities, governments, policymakers, and ICT companies.

Given the general consensus about the benefits of smart sustainable cities, coupled with the relevance and usefulness of the findings produced thus far in the field, the related research and development has been supported and advocated by the United Nations (UN), the European Union (UN), and the Organization for Economic Cooperation and Development (OECD), and other international organization and policy bodies (Bibri 2019b). Also, many city governments in ecologically advanced nations have recently set ambitious targets to smarten up their sustainable cities using a variety of initiatives and programs. Or, they have adopted the concept of smart sustainable cities by implementing big data applications to reach the required level of sustainability. Accordingly, it has become of crucial importance to develop and utilize new methods for measuring the smart performance of urban sustainability (e.g., Al-Nasrawi et al. 2015).

Big data science and analytics

We are living at the dawn of what has been termed as 'the fourth paradigm of science,' a scientific revolution that is marked by the recent emergence of big data science and analytics as well as the increasing adoption and use of the underlying technologies (large-scale compute, data-intensive techniques and algorithms, and advanced mathematical models) in scientific and scholarly research practices. Everything about science development and knowledge production is fundamentally changing thanks to the unfolding and soaring data deluge. Data-intensive science is a data-driven, exploration-centered form of science, where big data computing and the underpinning technologies are heavily used to help scientists and scholars manage, analyze, and share data for multiple purposes (Bibri 2019b). Data-intensive science as a paradigm and epistemological shift involves mainly two positions. The first position is a form of inductive empiricism in which the data deluge, through analytics as manifested in the data being wrangled through an array of multitudinous algorithms to discover the most salient factors concerning complex phenomena, can speak for itself free of human framing and subjectivism, and without being guided by theory (as based on conceptual foundations, prior empirical findings, and scientific literature). As argued by Anderson (2008), 'the data deluge makes the scientific method obsolete' and that within big data studies 'correlation supersedes causation, and science can advance even without coherent models, unified theories, or really any mechanistic explanation at all.' This relates to exploratory data analysis, which may not have pre-specified hypotheses, unlike confirmatory data analysis used in the traditional way of doing science that does have such hypotheses. The second position is data-driven science, which seeks to generate hypotheses out of the data rather than out of the theory, thereby seeking to hold to the tenets of the scientific method and knowledge-driven science (Kelling et al. 2009, p. 613). Here, the conventional deductive approach can still be employed to test the validity of potential hypotheses but on the basis of guided knowledge discovery techniques that can be used to mine the data to identify such hypotheses. It is argued that data-driven science will become the new dominant mode of scientific method in the upcoming Exabyte/Zettabyte Age because its epistemology is suited to exploring and extracting useful knowledge and valuable insights from enormous, relational datasets of high potential to generate more holistic and extensive models and theories of entire complex systems rather than parts of them, an aspect which traditional knowledge-driven science has failed to achieve (Kelling et al. 2009; Miller 2010).

In light of the above, the upcoming data avalanche is thus the primary fuel of this new age, which powerful computational processes or analytics algorithms are using to generate useful knowledge for enhanced decision-making and deep insights pertaining to a wide variety of practical uses and applications (e.g., developing more sustainable, efficient, resilient, livable, and equitable cities). The scope and impact of big data science and analytics will continue to expand enormously in the upcoming decades as scientific data and data about all branches of science become overwhelmingly abundant and ubiquitously available (Donoho 2015). Especially, significant progress has been made within data science, information science, computer science, and complexity science with respect to handling and extracting knowledge and insights from large masses of data, and these have been utilized within urban science (e.g., Batty et al. 2012; Bibri 2019a, b; Bibri and Krogstie 2017c; Kitchin 2014, 2016).

Big data computing is an emerging paradigm of data science, a typical model that is of multidimensional data mining for scientific discovery over large-scale infrastructure. It employs sophisticated computational methods to automatically extract useful knowledge and valuable insights from large masses of data—huge in volume, high in velocity, created in near or real-time, diverse in variety, exhaustive in scope, fine-grained in resolution, relational in structure, and extensible and scaleable in nature—using data science methods, processes, and systems. It has emerged as a result of the rise, advance, and prevalence of ICT as a global shift, as well as of the maturity and evolvement of the dominant ICT visions of ubiquitous computing into achievable and deployable computing paradigms, especially the IoT. However, it is not until recently that big data computing came to the fore and became of importance and relevance as a research area within smart sustainable urban planning and development (see, e.g., Al Nuaimi et al. 2015; Batty et al. 2012; Bettencourt 2014; Bibri 2018a, b, 2019a, b; Bibri and Krogstie 2016, 2017b; Khan et al. 2015; Kumar and Prakash 2014). The multifaceted potential of the smart city approach has been under investigation by the United Nations (2015c) through their study on 'Big Data and the 2030 Agenda for Sustainable Development,' to reiterate. On the whole, big data computing paradigm is clearly on a penetrative path across all the systems and domains of smart sustainable cities that rely on sophisticated technologies in their operational functioning, management, planning, development, and governance. In general, big data are regarded as the most scalable and synergic asset and resource for modern cities to enhance their performance on many scales. Unsurprisingly, there is a strong organizational, institutional, and governmental support for and commitment to big data technology-industry associations and consortia, business communities, scholarly and scientific research communities, policy bodies, and governmental agencies due to its tremendous (yet untapped) potentials and rapidly expanding success in relation to academic research and social practice.

As a new area of science and technology, 'big data science and analytics embodies an unprecedentedly transformative power—which is manifested not only in the form of revolutionizing science and transforming knowledge, but also in advancing social practices, catalyzing major shifts, and fostering societal transitions. Of particular relevance, it is instigating a massive change in the way both sustainable cities and smart cities are understood, studied, planned, operated, and managed to improve and maintain sustainability in the face of expanding urbanization' (Bibri 2019c, p. 79). To put it differently, these urban practices are becoming highly responsive to a form of data-driven urbanism that is the key mode of production for what have widely been termed smart sustainable cities whose monitoring, understanding, and analysis are increasingly relying on big data technologies.

In recent years, there has been a marked intensification of datafication. This is manifested in a radical expansion in the volume, range, variety, and granularity of the data being generated about urban environments and citizens (e.g., Kitchin 2014, 2015, 2016), with the primary aim of quantifying the whole of the city, putting it in a data format so it can be organized and analyzed. We are currently experiencing the accelerated datafication of the city in a rapidly urbanizing world and witnessing the dawn of the big data era not out of the window, but in everyday life. Our urban everydayness is entangled with data sensing, data processing, and communication networking, and our wired world generates and analyzes overwhelming and incredible amounts of data. The modern city is turning into constellations of instruments and computers across many scales and morphing into a haze of software instructions, which are becoming essential to the operational functioning, planning, design, development, and governance of the city. The datafication of spatiotemporal citywide events has become a salient factor for the practice of smart sustainable urbanism.

As a consequence of datafication, a new era is presently unfolding wherein smart sustainable urbanism is increasingly becoming data-driven. At the heart of such urbanism is a computational understanding of urban systems and processes that renders urban life a form of logical rules and algorithmic procedures—which is underpinned and informed by data-intensive-scientific approaches to urban science and urban sustainability, while also harnessing urban big data to provide a more holistic and integrated view and synoptic intelligence of the city (Bibri 2019b). This is increasingly directed towards improving, advancing, and maintaining the contribution of sustainable cities to the goals of sustainable development in an increasingly urbanized world. This relates to what has been dubbed data-driven smart sustainable urbanism (Bibri 2019b).

In a nutshell, the Fourth Scientific Revolution is set to erupt in cities, break out suddenly and dramatically, throughout the world. This is manifested in bits meeting bricks on a vast scale as instrumentation, datafication, and computerization are permeating the spaces we live in. The outcome will impact most aspects of urban life, raising questions and issues of urgent concern, especially those related to sustainability and urbanization. This pertains to what dimensions of cities will be most affected; how urban planning, design, development, and governance should change and evolve; and, most importantly, how cities can embrace and prepare for looming technological disruptions and opportunities.

The key external forces affecting the integration of the trends: the role of political action in smart sustainable cities

Smart sustainable cities are the product of socio-culturally-conditioned frameworks. This includes how and why the underlying data-driven processes and practices have emerged and become disseminated at the urban level and hence discursively constructed and materially produced through diverse socio-political institutions and organizations. In this respect, it is important to recognize the interplay between smart sustainable cities as a form of sustainability transition and other societal scales, as well as the links to political processes on a macro level, i.e., regulatory policies and governance arrangements. This relates to the dialectic relationship between societal structures and smart sustainable cities in the sense of each affecting and being affected by the other (see Bibri and Krogstie 2016 for a detailed discussion). The focus here is rather on how the former affects the latter, which is one of the objectives of the trend analysis. This one way relationship has been approached from a variety of perspectives, including transition governance, innovation system, and discourse analysis. From a transition governance perspective, government is one of the key actors involved in any form of sustainability transition through various governance arrangements, including funding schemes, research management (regulation of public research institutes), innovation and technology policies, regulatory standards, market manipulations, public–private collaborations and partnerships, and so on (e.g., Bibri 2015). In this respect, the government generates top–down pressure from regulation and policy and the use of market and other forms of incentives, while promoting, spurring, and stimulating the collective learning mechanisms by supporting innovation financially and providing access to the needed knowledge (Rotmans et al. 2001). Further, recommendations for smart sustainable cities as a major urban transformation, which entails a set of intertwined socio-technical systems and a cluster of interrelated discourses embedded in the wider socio-technical landscape, are unlikely to proceed without parallel political action (Bibri and Krogstie 2016). In general, drastic shifts to sustainable (and) technological regimes 'entail concomitantly radical changes to the socio-technical landscape of politics, institutions, the economy, and social values' (Smith 2003, p. 131).

Furthermore, political action is of influence in the context of smart sustainable cities as both a techno-urban discourse and an amalgam of innovation systems (Bibri and Krogstie 2016). Indeed, it is at the core of discourse theory (e.g., Foucault 1972) in terms of the material mechanisms and practices that can be used to translate urban visions into concrete strategies and projects and their institutionalization in urban structures (Bibri 2018a). Likewise, it is at the heart of the theoretical models of innovation system (e.g., Chaminade and Edquist 2010; Kemp 1997; Kemp and Rotmans 2005; Rånge and Sandberg 2015). Political processes represent the set-up under which dynamic networks of urban actors can interact within diverse industrial sectors in the development, diffusion, and utilization of knowledge and technology pertaining to smart sustainable urban planning and development.

Concerning the macro processes of regulation as one of the key components of political action, the act of regulating entails a set of principles, rules, or laws designed to govern urban behavior in terms of planning and development by carrying out legislations. Regulating city planning and development through policies is the responsibility of many different government departments and agencies. In other words, regulations are issued and enforced by various regulatory bodies formed or mandated by city governments to carry out the provision or intent of legislations. A city government affects urban planning and development through regulatory policies as a way to promote sustainability efforts. Most city governments have some regulations covering a variety of urban areas, including transport, traffic, mobility, natural environment, built infrastructure, green infrastructure, energy, land use, health, education, safety, as well as science and innovation in the context of sustainability.

On the whole, political action is of critical importance to, if not determining in, the emergence, insertion, functioning, and evolution of smart sustainable cities as an academic discourse, or rather to the construction, dissemination, and establishment of smart sustainable urban planning and development as an intellectual discourse. Related urban transformations have a quite strong governmental and policy support within ecologically advanced nations. The main argument is that smart sustainable cities—as an instance of sustainable urban development approach-are not an element closed in the 'ivory tower' of the research and industry communities, but they are influenced by the macro-political practices in connection with sustainable development and ICT innovation (Bibri 2018a). Such cities figure in many policy documents and agenda as well as political statements and argumentations, in addition to being used by many institutions and organizations of influential weight at the national and international levels, to reiterate. All in all, as a corollary of its dynamic interaction with academic and intellectual discourses, politics forces their emergence, insertion, functioning, and evolution (Foucault 1972). Bibri and Krogstie (2016) provide an account of some of the common political mechanisms used in this process, which represent facets of the operations that link smart sustainable cities and political action, including the following:

- Creating regulatory and policy instrument and incentives and carrying out legislations.
- Assigning scholarly roles and institutional positions to particular institutions and organizations, thereby authorizing them and legitimizing their actions as to R&D activities, technology and innovation policy formation, constructing and implementing new visions, and so on.
- Government involvement in projects and initiatives through funneling investments, providing positive incentives, advocating product and service adoption, organizing forums and symposiums, encouraging national and local programs, and devising comprehensive plans.
- Accumulating and preserving the relevant body of knowledge as well as disseminating and teaching concepts, visions, and principles, which is typically carried out inside research and innovation centers and higher educational institutions.

Furthermore, macro processes of political regulation are also of particular relevance to backcasting as a form of strategic urban planning and development related to sustainability and its advancement based on ICT as part of larger societal shifts. To move cities toward sustainability by improving their contribution to the goals of sustainable development using the innovative solutions and sophisticated approaches being offered by big data technology, policy actions should be, according to Bibri (2018a, p. 547), fostered through relevant principles and values, and the environmental, social, and economic impacts associated with sustainability need to be anticipated and assessed. As a normative scenario, backcasting in turn is a suitable and useful framework for supporting policymakers and facilitating their actions to guide sustainability transitions. The choice of such framework to develop scenarios of smart sustainable cities is supported and justified by its appropriateness to reach the policy targets (e.g., sustainable development goals) in tandem with societal development. In addition, backcasting scenarios may be capable of generating new policy directions needed if cities are to become smart sustainable (see OECD 2002 for guidelines towards environmentally sustainable transportation). Furthermore, the use of backcasting methodologies in futures studies assumes a vision of an evolutionary process of policy with a time frame of a generation or so, which is a basic principle to allow the policy actions to pursue the path towards, and potentially achieve, smart sustainable cities as a form of sustainability transition. The backcast of an alternative future is intended to reveal the relative implications of different policy actions and related targets and goals (Robinson 1982).

(b) The current situation

Sustainable cities—compact city and eco-city models of sustainable urban form

Deficiences, limitations, difficulties, fallacies. uncertainties, opportunities, and prospects Scholars and practitioners from different disciplines and professional fields have, over the past three decades or so, sought a variety of sustainable urban forms that could contribute to sustainability over the long run in response to the rising concerns about the environment and the socio-economic needs

(Bibri and Krogstie 2017a, b). The compact city (e.g., Jenks et al. 1996a, b; Hofstad 2012; Neuman 2005) and the eco-city (e.g., Joss 2010, 2011; Joss et al. 2013) are the most prevalent models of sustainable urban form and often advocated as more sustainable (e.g., Bibri 2018a, 2019b; Jabareen 2006; Kärrholm 2011; van Bueren et al. 2011; Rapoport and Vernay 2011). These models are compatible and not mutually exclusive, but there are some distinctive concepts and key differences for each one of them (Jabareen 2006). However, the challenge of meeting the goals of sustainable development has induced scholars, planners, policymakers, international organizations, civil societies, and governments to propose these two models as a way of redesigning and restructuring urban areas to achieve sustainability, which have been addressed on different spatial levels, including the regional level, the metropolitan level, the city level, the community level, the neighborhood level, and the building level. However, the underlying challenge continues to induce researchers, practitioners, and decision-makers to work collaboratively to enhance existing models of sustainable urban form across several spatial scales to achieve the requirements of sustainability and, ideally, to integrate its physical, environmental, economic, social, and cultural dimensions (Bibri 2019b). The ultimate goal of the endeavor is to develop more robust models of sustainable urban form. This has indeed been one of the most significant intellectual and practical challenges for more than three decades (e.g., Bibri 2018a, 2019b; Bibri and Krogstie 2017a, b; Jabareen 2006; Kärrholm 2011; Neuman 2005; Williams 2009). As concluded by Jabareen (2006, p. 48) after analyzing a distinctive set of the design principles and strategies as planning and development practices characterizing compact cities and eco-cities, among others, and how these can be compared and classified in terms of their contribution to sustainability, 'neither academics nor real-world cities have yet developed convincing models of sustainable urban form and have not yet gotten specific enough in terms of the components of such form.' This implies that it has been a challenging task to translate sustainability into the built form and, thus, evaluate the extent to which existing models of sustainable urban form contribute to the goals of sustainable development. Indeed, it is not evident which of these models are more sustainable and environmentally sound, although there seems to be in research on sustainable urban forms and anthologies a consensus on topics of relevance to sustainability (e.g., Bibri and Krogstie 2017b), In line with this argument, a critical review of such forms demonstrates a lack of agreement about the most desirable form in the context of sustainability (e.g., Jabareen 2006; Williams et al. 2000). Besides, 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 governments, planning experts, landscape architects, and so on are grappling with the dimensions of models of sustainable urban forms by means of a variety of design, planning, and policy approaches (Jabareen 2006; Kärrholm 2011). In addition, there is a lack of theory that can serve to compare different forms according to their contribution to the goals of sustainable development, as well as to evaluate whether a given urban form contributes to sustainability (Jabareen 2006). In a nutshell, not only in practice, but also in theory and discourse, has the issue of sustainable urban form been problematic and difficult to deal with as manifested in the kind of the non-conclusive, limited, conflicting, contradictory, uncertain, and weak results of research (Jabareen 2006; Kärrholm 2011; Neuman 2005; Williams 2009), particularly when it comes to the actual effects of the benefits of sustainability as assumed or claimed to be produced by design principles and strategies. Conclusively,'yet knowing if we are actually making any progress towards sustainable cities is problematic. In one sense, so much has been achieved in raising the profile of sustainability and sustainable cities over the last 30 years that the rate of change is inspiring… We seem to be going backwards to the extent that it is hard to see where there is any room for optimism. Urban

Table 2 Benefits of smart cities for sustainable cities

Data-driven applications for enhancing the outcome of the design principles and strategies underlying sustainable urban forms
Advanced simulation models for evaluating and optimizing such principles and strategies in terms of design scalability and planning flexibility that are necessary for responding to urban growth, environmental pressures, changes in socio-economic needs, discontinuities, and societal transitions
Urban intelligence functions for monitoring, planning, and designing sustainable cities
Data-driven smart urban metabolism for understanding the causalities governing urbanism and allowing citizens and city authorities to receive feedback on the system consequences of their choices
Innovative frameworks for smartening up urban metabolism to enable sustainable cities to maintain their levels of sustainability
Data-driven approaches to integrating urban systems, coordinating urban domains, and coupling urban networks
Data-driven applications for enhancing participation, equity, fairness, safety, and accessibility, as well as service delivery and efficiency in relation to the quality of life
Data-driven solutions for identifying risks, uncertainties, and hazards

problems…are becoming more acute as populations rise and resources become scarcer.' (Williams 2009, p. 2).

In addition, the conventional sustainable urban planning approach alone is no longer of pertinence as to ensuring or maintaining the effectiveness of sustainable urban forms with regard to the operation, function, and management of urban systems, as well as the integration and coordination of urban domains, in the context of sustainability due to the issues being engendered by the rapid urbanization. In relation to this argument, Neuman (2005) contends, in reference to the fallacy of compact cities, that conceiving cities in terms of forms remains inadequate to achieve the goals of sustainable development; or rather, accounting only for urban form strategies to make cities more sustainable is counterproductive. Instead, conceiving cities in terms of 'processual outcomes of urbanization' holds great potential for attaining these goals, as this involves asking the right question of 'whether the processes of building cities and the processes of living, consuming, and producing in cities are sustainable,' which raises the level of, and may even change, the game (Neuman 2005). The underlying argument is that while the layout or urban form can influence the environmental impact, it is rather the people and their behavior that ultimately determine the negative or positive environmental impact of urban areas. Monitoring, understanding, and analyzing the latter set of processes, in particular, can well be enabled by big data technology as an advanced form of ICT to further improve sustainability. Townsend (2013) portrays urban growth and ICT development as a form of symbiosis. However, the process-driven perspective as to be enabled by big data technology paves the way for a more dynamic conception of urban planning and design that reverses the focus on urban forms governed by static design and planning tools. This holds more promise in attaining the elusive goals of sustainable development (Neuman 2005). Existing models of sustainable urban form as to the underlying design principles and strategies seem to have failed to account for changes over time (Bibri and Krogstie 2017a, b).

In light of the above, it is timely and necessary to apply the innovative solutions and sophisticated approaches being offered by big data technology to deal with the challenges of sustainability as well as urbanization. Besides, a well-established fact is that cities evolve and change dynamically as urban environments, so too is the underlying design and planning knowledge that perennially changes in response to new emergent factors and changes. To put it differently, cities need to be dynamic in their conception, scalable in their design, efficient in their operational functioning, and flexible in their planning in order to be able to deal with population growth, environmental pressures, changes in socio-economic needs, global shifts/trends, discontinuities, and societal transitions (Bibri 2018a, 2019b). Durack (2001) argues for open, indeterminate urbanism due to its advantages, namely the tolerance and value of topographic, social, and economic discontinuities; continuous adaptation; and citizen participation, which is common to human settlements. This alternative approach to planning and development 'recognizes discontinuities and inconsistencies as life-affirming opportunities for adaptation and change, offering choices for the future in accordance with the true definition of sustainability' (Durack 2001, p. 2). This approach is also in line with backcasting as an approach to city planning and development where scenarios are used to explore future uncertainties, create opportunities, build capabilities, and improve decision-making processes, and moreover, when moving step by step towards the vision as visualized in Fig. 1, identify potential stumbling blocks on the way as well as assess policy pathways in terms of planning practices and development strategies necessary to achieve the desired future. Here comes the role of big data technologies and related sophisticated approaches in terms of their incorporation in urban planning and development due to their dynamic, synergistic, disruptive, and substantive effects. This pertains to urban intelligence and planning functions, which represent new conceptions of how smart sustainable cities function and utilize and combine complexity science and urban science in fashioning powerful forms of urban simulations models and optimization and prediction methods that can generate urban forms and structures that improve sustainability, efficiency, resilience, equity, and the quality of life (Bibri 2019b). In addition, In this respect, the provision of data from urban operations and functions is offering the prospect of urban environments wherein the implication of the way smart sustainable cities are functioning and operating is continuously available, and urban planning is facing the prospect of becoming continuous as the data deluge floods from different urban domains and is updated in real time, thereby allowing for a dynamic conception of planning and a scalable and efficient form of design (Bibri 2019b). This new approach also supports the idea of the dynamic conception of planning advanced by Neuman (2005), which emphasizes the processes of building cities and the processes of living, consuming, and producing in cities, rather than conniving cities in terms of forms, to reiterate. All in all, accepting indeterminacy demands much more than settling for the structures of an immutable order, and adopting sustainability as a sincere objective requires planning and developing cities 'not only in closer correspondence with nature, but also in recognition of the process of life itself' (Durack 2001).

Furthermore, 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), and thereby falls short in considering smart solutions and sophisticated methods in relation to operational functioning, planning, and design (Bibri 2019b; Bibri and Krogstie 2017b). The concept of urban sustainability has long been promoted by systems scientists using the pragmatic framework for urban metabolism; smart urban metabolism as an ICT-enabled evolution of such framework is being implemented to overcome some of its limitations in the context of eco-city (Shahrokni et al. 2015).

All in all, there are several critical issues that remain unsettled as well as under-explored for applied purposes with regard to the extent to which the challenges of urban sustainability can be addressed, despite the promotion of sustainable cities as a desirable goal within the context of policy and planning. In relation to this, Williams (2009) identifies two fundamental, critical, and interesting challenges pertaining to policies and monitoring strategies. The first is, the challenge of 'the vision': do we know what 'the sustainable city' is? And the second is, the challenge of change: do we know how to bring about 'sustainable urban development'? The latter entails developing a deeper understanding of the multi-faceted processes of change required to achieve more sustainable cities. This relates to the view that there are multiple processes of sustainable urbanism, and hence multiple visions of, and pathways to achieving, the sustainable city. On this note, Williams (2009, p. 3) adds that if we understand and respect this view, 'then we need to accept that making our cities more sustainable will be dependent on a similarly wide-ranging selection of actions. Some actions will be 'top-down' and require strong leadership and, perhaps, large-scale investment programs, other changes may be bottom-up, and rely on…shifts in behavior. These changes…will happen at different paces…, and at difference spatial scales.'

In the above line of thinking, it seems that the eco-city and the compact city as instances of sustainable cities are relatively well understood as a way of practically applying existing knowledge about what makes a city sustainable. Notwithstanding this dominant view in the prescriptive literature, what seems to prevail in research about the relationship between urban design and planning interventions and sustainability objectives is a subject of much debate (Bulkeley and Betsill 2005; Williams 2009). This means that realising an eco-city requires making countless decisions about sustainable (green) technologies, urban layouts, building design, and governance (Rapoport and Vernay 2011), just like the case for compact city (Kärrholm 2011; van Bueren et al. 2011). Furthermore, several studies (e.g., Guy and Marvin 1999; Jabareen 2006; Rapoport and Vernay 2011; van Bueren et al. 2011; Williams 2009) point to the issue of diversity underneath the various uses of the terms eco-city and compact city and shed light on the extent of divergence on the way projects and initiatives conceive of what eco-city and compact city models should be or look like. Indeed, in relation to the compact city, there are great differences between cities in terms of their urban form whose key elements can be distinguished: density, surface, land use, public transport infrastructure, and the economic relationship with the surrounding environment (van Bueren et al. 2011). Similarly, Rapoport and Vernay (2011) determine the differences in the way projects and initiatives conceive of what an eco-city should be. Guy and Marvin (1999) address the issue of the different models and pathways in terms of the diversity of sustainable urban futures. Williams (2009) offers a conceptualization of multiple pathways and processes of sustainable urbanism, and argues that a move to a deeper understanding of the interplay between social and technical solutions for sustainable cities is required. On the whole, there is a great deal of heterogeneity among city initiatives and projects that are considered to be sustainable cities. However, there is a need for recognizing that these multiple pathways and processes of sustainable urbanism need some coherence of purpose. Or else, there will be no conceptual 'anchor' in the event of the continuing conflicts and contradictions within sustainable urbanism thinking and practice, and to this anchor, sustainability principles, the sustainable use and wise management of natural resources, and equity and justice are of high relevance and usefulness. Regardless, understanding the multiplicity and diversity of socially constructed visions of sustainable urbanism is at the heart of stimulating and advancing research and practice, as long as it is driven by some coherence of purpose. In this respect, it has been interesting to witness how many socio-culturally specific ideas have been replicated in different locations across the globe, with little consideration or investigation of their appropriateness (e.g., Williams 2004, 2009). As asserted by Guy and Marvin (1999),'the role of research is to keep alive a multiplicity of pathways by opening a wider discourse and dialogue about the types of future we might be able to create.'

In relation to the ongoing efforts for smartening up sustainable urban forms using big data technology and its application, Bibri (2018a) points out that one of the key scientific and intellectual challenges pertaining to smart sustainable urban forms is to relate the underlying design principles and strategies and thus urban infrastructures to their operational functioning and planning through control, automation, management, and optimization. This relates to new urban intelligence functions as new conceptions of how such forms can function and utilize the complexity sciences in fashioning powerful new forms of simulation models and optimization and prediction methods (on the basis of big data analytics) that generate urban forms and structures that improve sustainability, efficiency, equity, and the quality of life (e.g., Bibri 2019b, d).

The main argument in the ongoing debate over sustainable urban forms as instances of sustainable cities is that urban systems are in themselves very complex in terms of functioning, operation, management, and planning, so too are urban domains in terms of coordination and integration as well as urban networks in terms of coupling and interconnection. Therefore, it is of high relevance to develop and employ innovative solutions for solving, and sophisticated approaches into dealing with, the challenges of sustainability and urbanization. This requires a blend of sciences for creating powerful design and engineering solutions, which ICT is extremely well placed to initiate for its application to urban systems, domains, networks, as well as related processes is founded on computer science, data science, urban science, and complexity science (e.g., Batty et al. 2012; Bibri 2018a, 2019b; Bettencourt 2014). Indeed, the role of ICT-enabled solutions in improving sustainability is becoming evident in light of the ongoing endeavors to advance both sustainable cities and smart cities (see, e.g., Al Nuaimi et al. 2015; Batty et al. 2012; Bibri and Krogstie 2017b; Bettencourt 2014; Kramers et al. 2014; Shahrokni et al. 2015).

All in all, despite the huge advances in different areas of knowledge and a number of impressive practical initiatives and programs in the realm of sustainable urbanism, there is still much more that needs to be done according to what arises of change on the ground. Hence and again, it has become of high significance and importance to theoretically and practically amalgamate the design concepts and planning practices of sustainability with the kind of sophisticated approaches and innovative solutions being offered by big data technology. The ultimate aim is to find more effective ways and more robust methods to improve, advance, and maintain the contribution of sustainable cities to the goals of sustainable development by assessing, optimizing, and enhancing the underlying strategies and approaches using cutting-edge technologies under what is labelled 'smart sustainable cities of the future.' This is important to embrace and pursue in an increasingly computerized and urbanized world. Especially, big data computing is offering great opportunities for, and unsurpassed ways of, effectively monitoring, understanding, analyzing, and planning such cities to achieve the optimal level of sustainability.

Smart cities: realizing the potential of smart cities of the future for advancing sustainability

Since the early 2010s, many scholars have highlighted the crucial role that ICT could play in sustainable urban development by decoupling resource consumption and environmental impact from economic growth while noting that the topic of ICT for sustainability has not attracted actionable political interest as of yet (Bibri 2019a, b). In looking at smart cities through the lens of strategic sustainable development, Colldahl, Frey and Kelemen (2013) note that smart cities hold great potential for advancing sustainability, as it is a powerful approach to enabling cities to become more sustainable due to the role of ICT in providing advanced solutions for addressing the complex challenges and pressing issues of sustainability, in addition to planning cities in a more innovative and forward-thinking manner. In reference to smart cities of the future, Batty et al. (2012) point out that cities can only be smart if there are intelligence functions that are able to integrate and synthesize the data to some purpose, ways of improving efficiency, sustainability, equity, and the quality of life. Future ICT in its form of big data technology and its application is concerned with researching smart cities not simply in terms of their instrumentation: 'constellations of instruments across many scales that are connected through multiple networks which provide continuous data regarding the movements of people and materials in terms of the flow of decisions about the physical and social form of the city' (Batty et al. 2012, p. 482), but also in terms of the way this instrumentation is opening up new opportunities for, and new forms of, advancing sustainability (Bibri 2019a, b).

In light of the above, smart cities have recently gained traction among many national governments and international policymakers as a promising response to the challenges of sustainable development in an increasingly urbanized world. Of particular relevance to emphasize here is that not until more recently that the development of smart cities came to the fore as a sort of panacea for solving the kind of wicked and intractable problems that characterize the practice of urbanism—thanks to the advent of big data technologies and their novel applications for advancing various aspects of sustainability (see, e.g., Al Nuaimi et al. 2015; Batty et al. 2012; Bibri 2018a; Bettencourt 2014; Marsal-Llacuna, Colomer-Llinàs and Meléndez-Frigola 2015). In fact, ICT has gained the recognition of offering unsurpassed ways to deal with the environmental, societal, and economic concerns of cities and hence to transform them into urban areas that can adapt to shocks since the mid 1990s, a few years after the widespread diffusion of the concept of sustainable development and the prevalence of ICT worldwide.

ICT has ever science been socially and discursively constructed as having an enabling and catalytic role in sustainable development and in envisioning its future form in the context of sustainable smart cities (Bibri 2019a). In smart cities, ICT is proposed as a set of solutions to urban challenges and issues of a complex nature, including sustainability and living standards (Batty et al. 2012; Hashem et al. 2016). In other words, but in more detail, smart cities represent an urban development paradigm that emerged in the late twentieth century as a result of the drive of cities to be more responsive to citizen needs through offering conditions conducive to promoting and enhancing the quality of life in an increasingly globalized world (Angelidou et al. 2017), and then to become more sustainable in an increasingly urbanized world (International Telecommunications Union (ITU) 2014; UNECE 2015b) with support of advanced ICT.

The assessment of smart cities builds on 'the previous experiences of measuring environmentally friendly and livable cities, embracing the concepts of sustainability and the quality of life but with the important and significant addition of technological and informational components' (Marsal-Llacuna, Colomer-Llinàs and Meléndez-Frigola 2015, cited in Ahvenniemi et al. 2017, p. 235). This relates particularly to big data technology, whose use spans many urban domains with regard to improving operational functioning, monitoring and optimizing infrastructures and facilities, reducing resource consumption, providing efficient and faster services to citizens to enhance the quality of their life, and streamlining planning and decision-making processes, all in line with the goals of sustainable development. By means of ICT innovations and thus advanced smart solutions, cities can well evolve in ways that can address environmental concerns and respond to socio-economic needs in a more strategic manner, as they are the incubators, generators, and transmitters of creative and innovative ideas (Bibri and Krogstie 2017a). The clear prospects of many major cities to overcome the complex challenges pertaining to sustainability and urbanization through the advanced forms of ICT is indeed the key reason why smart cities of the future has recently gained traction as a holistic urban development strategy among universities, research instituters, policymakers, city governments, and industries. When discussing ICT solutions for improving the different aspects of sustainability, reference is often made to smart cities of the future (see, e.g., Batty et al. 2012; Bibri 2018a) This is predicated on the assumption that ICT of pervasive computing offers great opportunities for monitoring, understanding, and analyzing various aspects of urbanity for operating, managing, and planning urban systems in ways that can be leveraged in the needed transition towards, and the advancement of, sustainability. It is in smart cities of the future that the key to a better world—which is held by emerging and future ICT—will be most evidently demonstrated (Batty et al. 2012). The underlying premise is that the use of ICT of pervasive computing, especially big data analytics and its application, is increasingly contributing to the further integration of urban systems and the effective assessment of their performance in terms of sustainability; facilitating collaboration and coordination among urban domains for energy and environmental efficiency gains; enhancing and mainstreaming ecosystem and public and social services; and pinpointing which kinds of networks need to be coupled (Bibri and Krogstie 2017a). This is due to the emerging wave of urban analytics for which big data constitute the fundamental ingredient as well as the opportunity of developing and utilizing new urban intelligence functions for urban monitoring, planning, and design (Bibri 2019b).

Smart sustainable cities: driving factors and research status

We live in a world where ICT has become deeply embedded and interwoven into the very fabric of the contemporary city, i.e., the operating and organizing processes of urban life and thus urban systems and domains are dominated by data and pervaded with information intelligence and high levels of automation and computation. It follows that it is high time for sustainable cities to smarten up in ways that can achieve the optimal level of sustainability. In particular, for sustainable cities to improve, advance, and maintain their contribution to the goals of sustainable development, they need to leverage their informational landscape by embracing what emerging and future ICT has to offer to make urban living more sustainable and attractive over the long run (Bibri and Krogstie 2017b). This is predicated on the assumption that emerging and future ICT offers tremendous potential for, and unsurpassed ways of, monitoring, understanding, analyzing, and planning smart cities and smart sustainable cities of the future to improve sustainability, efficiency, resilience, and the quality of life (Batty et al. 2012; Bibri 2018a). Bibri and Krogstie (2017a) summarize the main benefits of smart cities for sustainable cities (Table 2), which are reframed within the research need for advancing sustainable cities. The purpose is to provide insights into the relevance and usefulness of combining the strengths of sustainable cities and smart cities into an integrated holistic approach to urbanism.

The research on smart sustainable cities is garnering increased attention and rapidly burgeoning, and its status is consolidating as one of the most enticing areas of research today, especially within ecologically advanced nations, making the relevance and rationale behind the smart sustainable city debate highly significant with respect to the future form of urban planning and development. Smart sustainable cities as a holistic approach to urbanism aim primarily at substantiating and strengthening the growing potential and role of advanced ICT in enabling sustainable cities to enhance and maintain their performance in the face of urbanization.The way forward for developing and realizing smart sustainable cities is to amalgamate the sustainable city and smart city landscapes and approaches, a process which typically takes various forms depending on several factors, including objectives, requirements, and resources, as well as the social, cultural, national, and local contexts in which these elements are embedded and hence interpreted as related to urban projects and initiatives (Bibri 2019b). With this multidimensional context in regard, there are, and will be, different ways of conceptualizing and operationalizing the idea of smart sustainable cities and thus multiple pathways to achieve them. On this

Table 3 Problems, issues, and challenges pertaining to sustainable urban forms

What to solve, deal with, or overcome	Deficiencies, limitations, difficulties, fallacies. and uncertainties
Problems	Not only in practice but also in theory have sustainable urban forms been problematic and daunting to deal with as manifested in the kind of the non-conclusive, limited, conflicting, contradictory, uncertain, and weak results of research obtained. This is partly due to the use of traditional collection and analysis methods and data scarcity. These results pertain particularly to the actual effects and benefits of sustainability as assumed or claimed to be delivered by the design principles and strategies adopted in planning and development practices.
	Sustainable urban forms fall short in considering smart solutions within many urban domains where such solutions could have substantial contributions to the different aspects of sustainability
	Deficiencies in embedding various forms of advanced ICT into urban design and planning practices associated with sustainable urban forms
	Sustainable urban forms remain static in planning conception, unscalable in design, inefficient in operational functioning, and ineffective in management without advanced ICT in response to urban growth, environmental pressures, changes in socio-economic needs, global shifts, discontinuities, and societal transitions
	Realizing compact cities and eco-cities require making countless and complex decisions about green and energy efficient technologies, urban layouts, building design, and governance
	Divergences in and uncertainties about what to consider and implement from the typologies and design concepts of models of sustainable urban form
	Sustainable urban forms are in themselves very complex in terms of management, planning, design, and development, so too are their domains in terms of coordination and integration as well as their networks in terms of coupling and interconnection
	Sustainable cities and smart cities are weakly connected as ideas, visions, and strategies as well as extremely fragmented as landscapes at the technical and policy levels
	Sustainability goals and smartness targets are misunderstood as to their—rather clear—synergies
	There is a need for solidifying the existing applied theoretical foundations in ways that provide an explanation for how the contribution of sustainable urban forms to sustainability can be improved and maintained on the basis of big data technology and its applications.
	There is no strategic model for merging the informational and physical landscapes of the existing models of sustainable urban form.
Issues	In relation to spatial scales, the existing models of sustainable urban forms tend to focus more on the neighbourhood level than on the city level in terms of design and planning due to the uncertainties surrounding the design principles and planning practices as to their actual sustainability effects and benefits
	Conceiving cities only in terms of forms remains inadequate to achieve the goals of sustainable development. It should be informed by the processual outcomes of urbanization to attain these goals, as this involves asking the right questions related to the behavior of inhabitants; the processes of living, consuming, and producing; and the processes of building urban environments—in terms of whether these are sustainable
	Cities evolve and change dynamically as complex systems and urban environments, so too is the underlying knowledge of design and planning that is historically determined to change perennially in response to new factors
	In urban planning and policy making, sustainable cities have tended to focus mainly on infrastructures for urban metabolism—sewage, water, energy, and waste management while falling short in considering innovative solutions and sophisticated methods for urban operational functioning, planning, design, and development
Challenges	One of the most significant challenges is to integrate and augment sustainable urban forms with advanced technologies and their novel applications—in ways that enable them to improve, advance, and maintain its contribution to the goals of sustainable development.
	There are difficulties in translating sustainability into the built, infrastructural, and functional forms of cities
	There are difficulties in evaluating the extent to which the existing models of sustainable urban form contribute to the goals of sustainable development. It is not an easy task to even judge whether or not a certain urban form is sustainable
	One of the key scientific and intellectual challenges pertaining to sustainable urban forms is to relate the underlying typologies and infrastructures to their operational functioning and planning through control, automation, management, optimization, and enhancement
	There will always be challenges to address and overcome and hence improvements to realize in the field of sustainable cities, and this has much to do with the perception underlying the conceptualization of progress concerning cities. This centers around what we think we are aspiring to, what we assess 'progress' to be, and what changes we want to make

note, Al-Nasrawi et al. (2015) point out that there exists a competition on how to interpret and operationalize the concept of smart sustainable cities. As a corollary of it, there is a great deal of diversity among projects and initiatives considered to be smart sustainable cities in the form of ideas, arguments, or facts. The diversity underneath the various uses of the concept of smart sustainable cities implies that there are both convergences and divergences on the way projects and initiatives conceive of what a smart sustainable city should be in terms of which integrative perspective should be adopted. This can, though, translate into numerous opportunities towards new approaches to smart sustainable urban planning and development in order to mitigate or overcome the current fragmentation of the landscapes of sustainable cities and smart cities. Already, several topical studies (e.g., Angelidou et al. 2017; Bibri 2018a; Bibri and Krogstie 2017b; Kramers et al. 2014; Kramers, Wangel and Höjer 2016; Rivera et al. 2015; Shahrokni et al. 2015; Yigitcanlar and Lee 2013) have addressed the merger of these two landscapes or approaches from a variety of perspectives on how the different forms of advanced ICT can improve various aspects of sustainability, namely ubiquitous computing, big data computing, and/or context-aware computing to advance urban metabolism, urban form (planning and design), urban public and ecosystem services, urban operations and functions, urban strategies and policies, urban governance and citizen participation, or using simply ICT to optimize energy efficiency and provide solutions for everyday life practices. As an example with more detail concerning the conceptualization of the smart sustainable city, Yigitcanlar and Lee (2013) focus on 'ubiquitous-eco-city: a smart-sustainable urban form' whose principal premise is to provide a high quality of life and place to residents with low-to-no negative impacts on the natural environment with support of the state-of-the-art technologies in terms of management, planning, and development. The authors intend to put this premise into a test and address whether u-eco-city is a dazzling smart sustainable urban form that constitutes an ideal 21st century city model. In doing so, they place Korean u-eco-city initiatives under the microscope, as well as critically discuss their prospects in forming a smart sustainable urban form and becoming an ideal city model. Their conceptualization of u-eco-city is illustrated in Fig. 2. U-eco-city is an ICT and eco-technology (EcoT) embedded smart and sustainable city, where people can access both digital and eco-services based on the technology convergence between ICTs and EcoTs (Lee 2009).

All the above endeavors reflect the characteristic spirit and prevailing tendency of the ICT-sustainability-urbanization era as manifested in its aspirations for directing

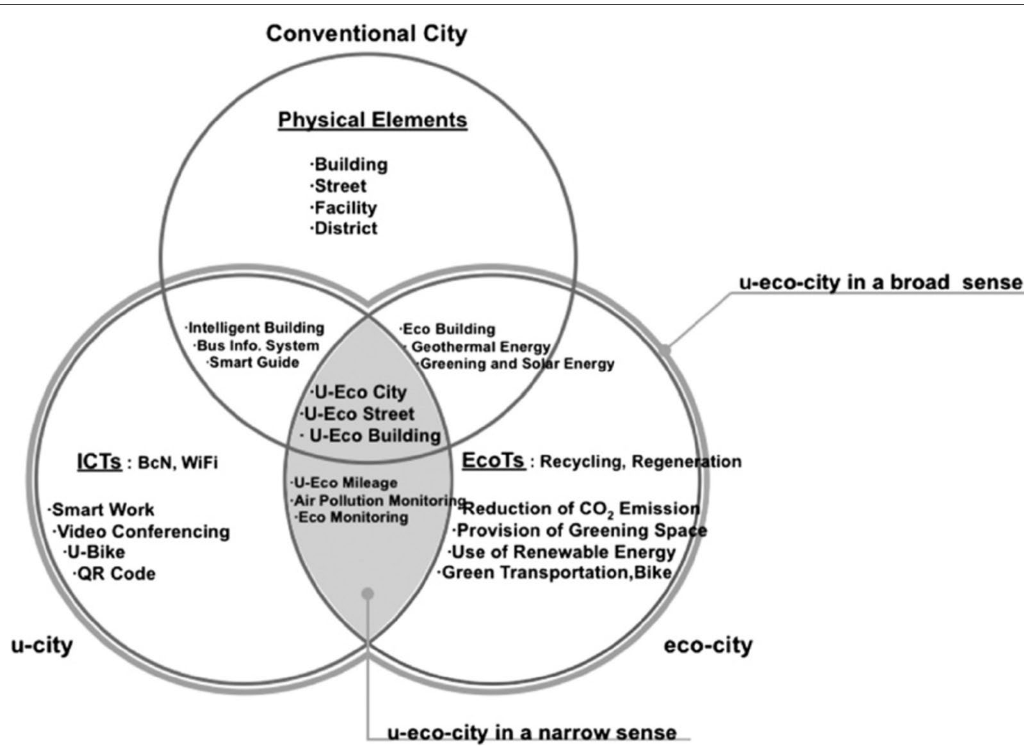

Fig. 2 Relation between ubiquitous-city and eco-city in the context of u-eco-city (source: Yigitcanlar and Lee (2013))

the advances in ICT towards addressing and overcoming the challenges of sustainability and urbanization in the context of smart sustainable cities of the future. All in all, smart sustainable cities open new windows of opportunity for doing a lot more to advance sustainability with support of emerging and future ICT, and offer the types of insights and practical ideas that scholars, practitioners, and policymakers need in order to bring about sustainable urban development.

Furthermore, several ecologically advanced nations aim at or strive for being associated with the concept of smart sustainable cities as a sign of societal development. While some countries claim to have evolved towards smart sustainable cities, and others to have developed the technical infrastructure needed for smart sustainable cities and focused on sustainable development policies, there is no hard evidence to confirm these claims, as there is still no assessment models or advanced frameworks to measure the performance of such cities (Al-Nasrawi et al. 2015). In this respect, Al-Nasrawi et al. (2015) suggest a multidimensional methodological model that assists in evaluating the smartness level of a city while being sensitive to its context, and provide further contribution by combining sustainable and smart dimensions of a city.

In addition, the European Union supports the movement of its cities to being smart (and) sustainable; hence its conscious efforts to drive this by investing in various city initiatives. In relation to the European Innovation Partnership on Smart Cities and Communities website, there are 34 EU projects in different cities concerned with mitigating the various pressures that arise from urban growth and sustainable development. This led to the meeting of the Environment Agency Austria (EAA), the International Telecommunication Union (ITU), EU member states, and other stakeholders in Geneva to come up with and discuss a set of standard indicators to assess a city's path to being smart and sustainable (UNECE, 2015a, b). The Europe 2020 targets serve as a challenge for European cities to improve their competitiveness in terms of how smart, sustainable, and inclusive they are (European Commission 2010b). There has been several efforts toward measuring the systematic progress of cities in achieving these targets, as well as comparing progress made with other cities. One of these efforts is city rankings, which serves as a benchmark that cities can use to measure their overall progress toward well defined targets, as well as to define goals and strategies for future development (Debnath et al. 2014). The indicators jointly proposed by the United Nations Economic Commission for Europe (UNECE) and the International Telecommunications Union (ITU) to rank European capital cities are being used to gauge how smart and sustainable these and other cities are.

All in all, the prospect of smart sustainable cities is becoming the new reality, especially within ecologically advanced nations (Bibri and Krogstie 2016), owing to the underlying global driving factors and prevailing and emerging trends. This development will undoubtedly continue, as it is supported by strong external forces and societal structures affecting the phenomenon of smart sustainable cities. Moreover, it constitutes part of rather larger societal shifts (i.e., sustainability transitions) with far-reaching and long-term implications. This is anchored in the recognition that there are fascinating possibilities and immense opportunities to exploit from deploying and implementing the innovative solutions and sophisticated approaches being offered by big data technology and its novel applications.

The field of smart sustainable cities is a fertile area of interdisciplinary and transdisciplinary research, entailing clearly a wide spectrum of explorable horizons with many intriguing questions awaiting scholars and practitioners from different disciplines and fields (Bibri and Krogstie 2017a). This is underpinned by the recognition that it provides a unique opportunity to take stock and harness the plethora of lessons learned from almost three decades or so of research and planning devoted to seeking, developing, and implementing sustainable cities, and about one decade or so for developing and applying advanced technologies to advance sustainability in smart cities. Therefore, it is high time to leverage the theoretical and substantive knowledge accumulated hitherto on smart sustainable urban planning and development from all kinds of research endeavors as well as projects and initiatives that have contributed to making urban living sustainable and smart.

The outcome of part 2 of strategic problem orientation

Long-lasting trends The key prevailing and emerging trends identified include:

- Global shifts: sustainability, ICT, and urbanization.
- Intellectual discourses: sustainable urbanism, smart urbanism, data-driven urbanism, and sustainable development.
- Academic discourses: sustainable cities, smart cities, and smart sustainable cities.
- Computing paradigms: pervasive computing, ubiquitous computing, the IoT, and big data computing.
- Scientific paradigms: data-intensive science.
- Technological innovations: big data technologies, analytics, and applications.

The dynamic interplay between these varied forms of trends, which will undoubtedly continue to evolve simultaneously and affect one another in a mutual process for many years yet to come, is the backcloth against which many recent urban innovation and transition endeavors have materialized, and hence numerous opportunities have been, and continue to be, created and explored in the context of what has been dubbed data-driven smart sustainable cities. In particular, these forms of trends are shaping and driving not only the materialization of such cities as a leading paradigm of urbanism, but also their evolvement, success, expansion, and evolution.

Problems, issues, and challenges related to sustainable cities Sustainable urban forms have always been problematic and daunting to deal with. In view of that, the intellectual challenge to produce a theoretically and practically convincing model of sustainable urban form with clear components continues to induce scholars, academics, planners, scientists, and even real-world cities to create a more successful and robust model of such form. In addition, the contribution of the existing models of sustainable urban form to sustainability has, over the last three decades or so, been subject to much debate, generating a growing level of criticism that essentially questions their practicality and added value.

Developing a model for smart sustainable cities of the future is aimed at improving, advancing, and maintaining the contribution of sustainable urban forms to the goals of sustainable development with support of big data technologies and their novel applications as advanced forms of ICT. This is due to the underlying potential for enhancing and optimizing urban operations, functions, designs, services, strategies, and practices in line with the goals of sustainable development, as well as for attempting to solve a number of problems, addressing key issues, and overcoming complex challenges in the context of sustainable urban forms. These are distilled and compiled in Table 3 from "Deficiencies, limitations, difficulties, fallacies. uncertainties, opportunities, and prospects" section.

Expected development The main expected developments identified are believed to be already happening or to arrive soon, and include the following:

- Instrumentation, computerization, and computation are routinely pervading the very fabric of sustainable cities.
- Sustainable cities are becoming increasingly datafied and thus dependent upon their data to operate properly—and even to function at all with regard to many domains of urban life—datafication.
- Sustainable urban practices (operational functioning, planning, design, development, and governance) are becoming highly responsive to a form of data-driven urbanism.
- Sustainable cities are increasingly embracing big data technologies and their novel applications to improve, advance, and maintain their contribution to the goals of sustainable development towards achieving the optimal level of sustainability.
- Sustainable cities and smart cities are becoming more and more connected as approaches.
- Smart sustainable cities are gaining foothold and traction worldwide as a promising response to the challenges of sustainability and urbanization.
- Data-driven urbanism is increasingly becoming the mode of production for smart sustainable cities, i.e., a new era is presently unfolding wherein smart sustainable urbanism is increasingly becoming data-driven.
- Data-intensive science as a fourth scientific paradigm is drastically changing how urban analytics and urban studies are done in relation to sustainability science and knowledge.

Discussion and conclusion

Smart sustainable cities as the leading paradigm of urbanism are seen as the most important arena for sustainability transitions. They are well positioned to instigate major, and make significant contributions to, societal transformations by linking sustainable development with technological development. Drastic changes of this kind require long-term versions and thus strategic planning and development where backcasting studies can play a key role in guiding decision-making processes and assessing policy pathways necessary to achieve such visions. Moreover, backcasting studies allow for a better understanding of future opportunities and exploring the implications of alternative development paths that can be relied on to avoid the impacts of the future. When applied in sustainability planning, backcasting can also increase the likelihood to envision certain changes (Holmberg and Robèrt 2000). There is a belief that future-orientated planning can change development paths. The interest in the future of the smart sustainable city is driven by the aspiration to transform the continued urban development path into a sustainable future.

This paper detailed the two parts of strategic problem orientation by answering the guiding questions for Steps 1 and 2 of the futures study being conducted. Important to note, as there are many questions that guide the 6 steps of the backcasting methodology applied in this futures study that need to be answered in a form entailing description, elaboration, explanation, analysis, synthesis, investigation, design, and so on, it is deemed more appropriate to divide the whole scholarly backcasting endeavor into several papers.

Concerning Step 1, the first part of the strategic problem orientation of the backcasting study, the outcome is straightforward. We determined the aim, purpose, and objectives of the backcasting study in relation to the proposed model for smart sustainable cities of the future, and then we specified related sustainability targets and goals. As regards Step 2, the second part of the strategic problem orientation of the backcasting study, a number of a number of different, yet related, forms of trends associated with the phenomenon of smart sustainable cities were identified, described, and elaborated. In addition, the interrelationships between these trends were discussed in relevance to the aim of the futures study. The forms of trends identified include global shifts, intellectual discourses, academic discourses, computing paradigms, scientific paradigms, and technological innovations. Also, envisioning how smart sustainable cities will evolve was supported by the status of the recent and ongoing research endeavors in the field as involving most of the trends identified in this context. Moreover, the causes triggering the various forms of trends to emerge were examined, so was how and why they will continue in that direction. In addition, the key external forces affecting these forms of trends were elucidated and discussed while highlighting that these trends and their amalgamation constitute part of larger societal shifts with far-reaching and long-term implications, namely sustainability transitions.

Remaining on Step 2, the most relevant outcome of the current situation shows that sustainable cities are currently associated with a number of problems, issues, and challenges, and therefore need to embrace what smart cities of the future have to offer in terms of big data technologies and their novel applications in order to improve, advance, and maintain their contribution to the goals of sustainable development. Especially, one of the most significant challenges at the moment is to produce a theoretically and practically convincing and robust model of sustainable urban form with clear components—and seamlessly integrated with advanced technologies and their novel applications (Bibri and Krogstie 2017b). Besides, a large part of research in the area of smart sustainable cities focuses on exploiting the potentials and opportunities of advanced technologies as an effective way to mitigate or overcome the issue of sustainable cities and smart cities being extremely fragmented as landscapes and weakly connected as approaches.

The issue of sustainable urban forms has been problematic. Indeed, the debate over the ideal or desirable urban form dates back to the end of the 19th century, and obviously, the concept of sustainable development revives it and develops existing models of sustainable urban form further by enhancing them with the planning principles and ecological design of sustainability (Jabareen 2006). Again, smart development as being predominately driven by big data technology has recently revived this debate, and is attempting to enhance existing models of sustainable urban form by smartening up the performance of the underlying design principles and strategies, thereby increasing their contribution to sustainability. It has become of high pertinence and importance to augment sustainable urban forms with big data technologies and their novel applications (Bibri and Krogstie 2017b).

Building smart sustainable cities based on big data computing is of a strategic value as to solving many of the complex challenges and pressing issues of sustainability and urbanization. Many sustainable cities across the globe have already started to exploit the potential of big data applications in relation to diverse urban systems and domains. We stand at a threshold of new era where big data science and analytics is drastically changing the way sustainable cities are studied, understood, planned, designed, developed, and governed. The ultimate goal is to improve, advance, and maintain their contribution to sustainability by employing more effective ways to monitor, understand, probe, and plan them. However, there are currently numerous challenges and concerns that need to be addressed and overcome in this new area of science and technology in relation to smart sustainable urbanism for achieving the desired outcomes (see Bibri 2019a for a detailed account).

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Authors' contributions
Both authors read and approved the final manuscript.

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4. Master of Science in computer and systems sciences with a major in decision support and risk analysis.
5. Master of Science in entrepreneurship and innovation with a major in new venture creation.
6. Master of Science in strategic leadership toward sustainability.
7. Master of Science in sustainable urban development.
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2. The Shaping of Ambient Intelligence and the Internet of Things: Historico–epistemic, Socio–cultural, Politico–institutional and Eco–environmental Dimensions (301 pages), Springer, 11/2015.
3. Smart Sustainable Cities of the Future: The Untapped Potential of Big Data Analytics and Context–Aware Computing for Advancing Sustainability (660 pages), Springer, 03/2018.
4. Big Data Science and Analytics for Smart Sustainable Urbanism: Unprecedented Paradigmatic Shifts and Practical Advancements (505 pages), Springer 06/2019.

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