smart cities

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Review

Insights from Smart City Initiatives for Urban Sustainability and Contemporary Urbanism

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Highlights:

- Smart city initiatives are varied but primarily focus on governance and environment, with less attention to other critical dimensions needed for sustainable urban practices.
- Smart city initiatives heavily rely on ICT for managing urban operations but lack comprehensive and inclusive assessment studies on their sustainable and social benefits.

Implications of the Main Findings:

- The findings highlight the need for more holistic frameworks in smart city approaches to efficiently address urban sustainability challenges and improve urban practices.
- Standardized assessment methods are needed for evaluating the benefits of smart technologies on sustainable development and urban practices.

Abstract: Urbanization growth poses various challenges, such as congestion, pollution, and resource consumption, prompting city planners and governments to adopt smart systems to manage these issues more efficiently. Despite widespread adoption, there is no consensus on the defining attributes of smart cities, particularly regarding their role in urban sustainability and contemporary urbanism. This paper provides a literature review to understand the implications of smart city initiatives for sustainable urban planning, focusing on practices in Singapore, Helsinki, Barcelona, and Medellin. Based on 71 publications surveyed from Scopus and Web of Science, this paper evaluates smart, sustainable initiatives undertaken in these four cities across six smart domains: mobility, governance, environment, people, living, and economy. This review shows that most studies focus on Barcelona and Singapore, particularly in the domains of smart environment and governance. Despite differing urban contexts, the notion of "smart" is closely tied to using information and communication technologies to drive urban operations. This analysis identifies a lack of assessment studies on the benefits of smart cities in terms of urban sustainability and a lack of holistic approaches to address the complex challenges cities face in achieving sustainable development.

Keywords: smart cities; sustainability; urban planning; planning practices

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1. Introduction

Today, 56% of the world's population lives in urban areas [1]. Projections indicate that urbanization and global population growth could add another 2.2 billion people to urban areas over the next few decades, potentially raising the world's urbanization rate to 68% by 2050 [1]. This rapid urbanization presents a myriad of global challenges, including congestion, pollution, greenhouse gas (GHG) emissions, depletion of natural resources, environmental degradation, inadequate infrastructure, urban poverty, and high land prices [2]. These challenges have prompted urban planners, decision-makers, and researchers to explore ways to make cities more livable and sustainable.

Urban sustainability is defined as a city's ability to successfully operate across environmental, social, and economic domains simultaneously [3]. Urbanism plays a crucial role in shaping the development of urban areas to address these challenges. Generally, urbanism concerns itself with the form and function of cities, providing a framework for analyzing and understanding urban environments through integrated and design-oriented approaches [4,5].

A smart city (SC) is a contemporary urban approach that emerged in the late 1990s [6,7], leveraging technology and data-driven solutions to enhance urban efficiency, sustainability, and livability [8,9]. SCs have been characterized through tools such as information and communication technologies (ICTs), Internet of Things (IoT), open data, public–private collaboration, and competition. They often comprise six components, which include smart mobility, smart environment, smart governance, smart living, smart people, and smart economy [10–13]. Although SCs are widely recognized for their potential to bring multiple urban benefits to all these dimensions, there is no clear consensus on their precise definition or defining characteristics [7,14]. The concept of SCs has evolved alongside technological advancements and changing urban needs, resulting in a wide range of interpretations and initiatives [6,7]. It encompasses a variety of attributes, depending on the context in which it is applied [14–16]. This diversity often leads to varied priorities and objectives within SC initiatives, ranging from environmental sustainability and social equity to economic development and administrative efficiency [17,18]. As a result, SC initiatives encompass not only technological innovations but also broader dimensions of urban development and sustainability [7,19,20].

The emergence of the term "smart sustainable" seems to indicate a strong association between the concepts of smartness and urban sustainability. According to the International Telecommunication Union (ITU), a smart sustainable city is "an innovative city that uses ICT and other means to improve quality of life, the efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects" [21]. Within this context, SCs have been viewed as a way of achieving more sustainable urban development [22], while other authors argued that to be smart, cities need to be sustainable first [20]. However, the extent to which a SC contributes to urban sustainability is unclear [23] and there is a substantial lack of research exploring the benefits of SC initiatives in urban sustainability [24]. Much of the existing SC literature is concentrated in the fields of computer and engineering sciences, leaving urban sustainability issues underexplored [10]. It has been argued that the SC literature frequently prioritizes technological and economic concerns over environmental considerations, creating tensions between the concepts of smart and sustainable cities [10,25]. Thus, there is a need to review and examine the contribution of SC approaches on urban sustainability [22] and, more specifically, whether smart urbanism, which serves as a valuable framework for evaluating contemporary urbanism [24], truly promotes sustainable development. There are various reviews on the definition and practice of SCs [26–28], but there have not been any systematic review studies to discuss the implications of SC initiatives on urban sustainability and smart urbanism, particularly through a comparative lens across diverse cities and SC domains. Further, there is a need for a deeper understanding of how SC policies affect different urban groups and how open data platforms can foster innovative applications and practices for smart urban development [29]. Furthermore, while the key focus of SC agendas has been on the replicability and scalability of urban solutions [18], this emphasis has exposed significant limitations as universal solutions often fail to account for the specific needs and contextual conditions of individual cities. Müller et al. [18] suggest that rather than prioritizing scalability, it would be more effective to focus on the learning potential of diverse urban contexts. Context-specific insights and adaptive strategies are better suited to addressing the unique challenges each city faces.

In response to the research gaps identified, this paper seeks to explore the implications of SC initiatives for sustainable urban planning, emphasizing the learning potential from

different urban contexts. By analyzing SC initiatives in four cities—Singapore, Helsinki, Barcelona, and Medellin—across different continents, this study seeks to uncover how these strategies can be tailored to varied urban environments, providing valuable insights into their broader impact on urban sustainability and contemporary urban practices. The selection of these cities provides an opportunity to explore the distinct challenges each urban context presents and evaluate how local conditions shape the implementation and outcomes of SC initiatives. This approach aligns with Müller et al.'s [18] argument, which advocates for focusing on context-specific insights and learning opportunities rather than replicating one-size-fits-all solutions. By exploring how different cities adapt SC strategies to their unique socioeconomic, cultural, and environmental conditions, this study aims to deepen the understanding of adaptive smart urbanism. This approach can shed light on how SC practices intersect with sustainable and smart urbanism, offering insights into strategies that promote more adaptive and inclusive urbanism. The findings have the potential to promote SC strategies that are not only technologically innovative but also contextually relevant, advancing sustainable planning and urbanism worldwide. By contributing to the discourse on integrating smart technologies with sustainability and highlighting the learning potential from diverse urban contexts, this research supports the development of SC initiatives that better address the unique needs and challenges of cities in varying global settings.

2. Materials and Methods

2.1. Rationale for Selecting the Case Studies

This paper aims to review and analyze SC initiatives in Barcelona, Helsinki, Medellin, and Singapore, and to assess their contributions to urban sustainability. The selection of these cities as case studies is based on four main reasons. First, they are located on three different continents, ensuring a broad geographic representation. Second, the four selected cities represent both developed and developing countries, providing a diverse range of urban contexts and experiences. The goal was to capture the varied challenges and opportunities that different economic contexts present in SC development. Third, Singapore and Helsinki are among the top-ranking SCs globally, placing within the top ten in the recent Smart City Index of 2024, while Barcelona occupies a lower, though still notable, position in that ranking [30]. Although Medellin does not rank as highly, it is a significant case study due to its innovative approach to SC development in the Global South. Fourth, each of these cities has pioneered unique approaches to sustainable urban planning: Singapore is renowned for its efficient use of technology in managing urban infrastructure; Helsinki, a leading example from Northern Europe, is recognized as the continent's most innovative city and a top destination for foreign investments, boasting the best digital twin in the Kalasatama neighborhood [26]; Barcelona provides a Southern European perspective, aiming to become the most connected city globally through heavy investments in IoT applications [31]; and finally, Medellin has gained prominence amongst cities in the Global South due to urban management initiatives, such as social urbanism, which have transformed the city [32]. Thus, this selection was intended to include cities at different stages of SC maturity that can potentially offer a comprehensive understanding of how SC initiatives and sustainable urban planning practices have been implemented across diverse urban contexts.

2.2. Literature Review Process

The review process followed the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) guidelines. Figure 1 illustrates the key steps: (i) identification of the relevant literature; (ii) screening based on predefined criteria; (iii) data extraction from selected studies; and (iv) categorization of articles by city and SC domain.

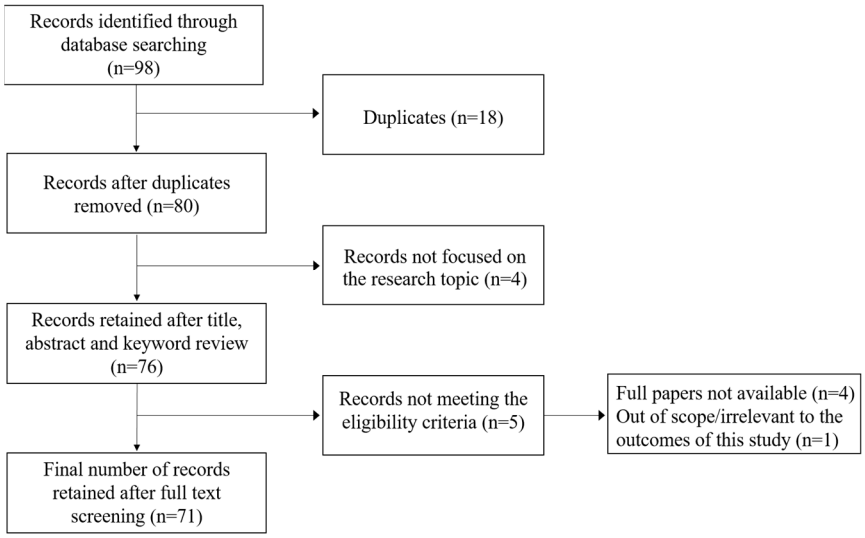

Figure 1. Flow diagram of literature review.

To initiate the search process, Scopus and Web of Science databases were selected and queried due to their established reputation and comprehensive coverage [24]. The search employed the following keywords in the title, abstract, and keywords fields: (smart cities) and (Singapore or Helsinki or Barcelona or Medellin) AND (urban sustainability or smart sustainable or smart sustainability), across all publication fields. The search scope was limited to peer-reviewed English-language journal articles, spanning from the inception of electronic bibliographic databases to 31 May 2024.

In the second step, the reference lists of the selected articles were reviewed to identify any additional studies that may have been missed out. The screening process involved evaluating the eligibility of the retrieved articles. Firstly, duplicate publications from the two databases were removed. Then, the titles, abstracts, and keywords were manually checked to determine if the publications predominantly addressed the topic of SCs in the four selected case studies. Papers not focused on the research topic or where the four analyzed cities appeared incidentally were excluded. Subsequently, the papers underwent independent double-screening by two members of the research team. Documents without full texts were also removed from the analysis, as well as studies that were out of scope or irrelevant to the objectives of this study. Any disagreements were resolved through discussion and consensus among the authors.

After selecting the articles, relevant data were extracted. This included the article title, authors, affiliations, keywords, year of publication, publication title, number of citations, and full texts. The extracted information was then used to conduct a concise bibliometric analysis to assess research trends in this area and identify primary sources, authors, and affiliated research institutions.

Lastly, the extracted articles underwent classification based on their respective SC domains and initiatives adopted in each city. Initially, the literature was categorized by city, and then the findings were organized into the following six major SC domains described in the Introduction, which have been widely used in the literature to evaluate SC initiatives: smart mobility, smart environment, smart governance, smart people, smart living, and smart economy [10–13]. This categorization was performed to extract key urban sustainability initiatives and practices implemented in each of the four SCs.

Following the described steps, a total of 98 references were identified from the Scopus and Web of Science databases. After removing 18 duplicates, 80 documents underwent individual screening based on their titles, abstracts, and keywords. Four papers were excluded because they focused on cities in Abu Dhabi, Iraq, South Korea, and Venezuela, which were not within the scope of this study. Thus, 76 records underwent eligibility assessment through full-text screening. Of these, four papers could not be retrieved due to

lack of full access, while another paper was excluded after full-text screening because its content was deemed irrelevant or out of scope for the objectives of this review. As a result, a total of 71 records were eligible for inclusion in this review.

3. Results

3.1. Overview of the Selected Papers

The 71 eligible papers were published between 2013 and 2023. As depicted in Figure 2, the topic has garnered increasing attention in recent years, with 59% of the documents published in the last four years. All retrieved documents were published as articles in a total of 49 journals spanning various subject areas. The journals with the most publications included *Sustainability* (10 publications), *Sustainable Cities and Society* (4), *Cities* (3), *IEEE Access* (3), *Journal of Urban Technology* (3), and *Sensors* (3).

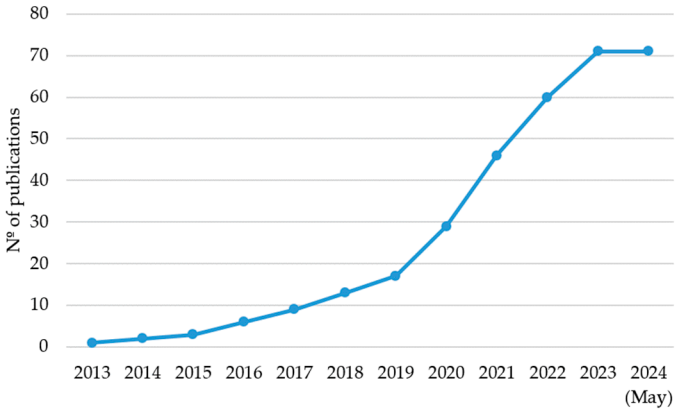

Figure 2. Number of papers (accumulated) published by year.

The 71 documents contained about 380 keywords. The most frequently occurring keywords were *smart cities* (appearing in 62 papers), *sustainability* (12), *sustainable cities* (10), *urban governance* (8), *environment* (6), *Internet of Things* (6), *Singapore* (6), and *smart sustainable cities* (6).

The universities in the four selected cities are among the institutions with the most publications on the researched topic. From Spain, these include the University of Barcelona, the Open University of Catalonia, the Autonomous University of Barcelona, and Ramon Llull University; in Finland, they are the University of Helsinki, Aalto University, the University of Vaasa, and the Lappeenranta-Lahti University of Technology; in Colombia, they are the Colombian American University Corporation and the National University of Colombia; and from Singapore, this includes the National University of Singapore.

According to the Scopus and WoS databases, the most cited documents in this field until May 2024 are the article by Zygiaris [33] with 465 citations, followed by the studies by Angelidou [34] with 249 citations, and Mora et al. [35] with 206 citations.

Focusing on the analysis of the four selected cities, Table 1 presents the distribution of the retrieved papers by city.

Table 1. Returned studies that include the four cities.

Analyzed Cities	References
Barcelona	[10,27,33–63]
Helsinki	[13,26,35,36,64–73]
Medellin	[32,59,74–76]
Singapore	[3,11,12,25,26,28,34,43,52,56,62,74,75,77–93]

Barcelona was featured in 40% of the retrieved documents, Singapore in 37%, Helsinki in 17%, and Medellin in 6%. This suggests that Barcelona and Singapore have significant in-

volvement and leadership in SC initiatives. The search also revealed that 52% of the studies focused on more than one city (either one of the three or other cities altogether), indicating that comparative studies across various SCs are common within this research topic.

3.2. Findings

3.2.1. Smart City Initiatives and Urban Sustainability Practices

This subsection analyzes the SC initiatives and corresponding urban sustainability practices adopted in the four cities across the six described domains: smart mobility, smart environment, smart governance, smart people, smart living, and smart economy. Table 2 provides a summary of the analyzed papers categorized by these domains (papers that cover more than two domains are classified as "multidimensional").

Table 2. Smart city domains explored in the searched documents.

References	Mob.	Env.	Gov.	Peo.	Liv.	Eco.	Multi.
Al-Saffar [37]							X
Ang-Tan and Ang [77]			X				
Angelidou [34]							X
Anttiroiko [64]			X				
Sánchez-Vaquerizo [38]	X						
Bibri and Krogstie [39]		X					
Bibri and Krogstie [40]							X
Bolici and Mora [41]							X
Calzada [42]			X	X			
Chib et al. [78]				X		X	
Crumpton et al. [12]		X	X				
Csukás and Szabó [36]							X
Della Corte et al. [36]			X			X	
Demirel [43]			X				
Demirel and Mülazımoğlu [44]			X				
Drapalova and Wegrich [45]			X				
Echendu and Okafor [79]							X
Fernández and Peek [10]		X					
Fonseca et al. [46]	X			X			
Garau et al. [65]		X					
Górna and Górny [80]							X
Härkönen et al. [66]					X		
Hartmann and Garcia [81]		X				X	
Hernández et al. [67]							X
Icasiano and Taeihagh [82]			X				
Iryna et al. [83]							X
Javed et al. [68]							X
Joo [84]			X				
Kenger et al. [85]							X
Kutty et al. [69]					X		
Lapinskaitė et al. [70]							X

Table 2. *Cont.*

References	Mob.	Env.	Gov.	Peo.	Liv.	Eco.	Multi.
Lim and Taeihagh [86]	X						
Lopes [74]			X				
Mancebo [47]				X			
Mann et al. [48]							X
March and Ribera-Fumaz [49]		X					
Martinez and Mahajan [75]		X					
Mora et al. [35]							X
Nicolas et al. [13]							X
Noori et al. [50]			X	X			
Papyshev and Yarime [87]	X						
Peyman et al. [51]	X						
Phumpiu and Rivera-Kuri [52]							X
Pira [27]					X		
Quijano et al. [71]							X
Ricci and Mariano [53]							X
Ringenson and Höjer [54]		X					
Sanyal et al. [55]							X
Sethi and Mittal [88]		X					
Shamsuzzoha et al. [26]							X
Shmelev and Shmeleva [3]		X				X	
Shmelev and Shmeleva [56]							X
Smith and Martín [57]			X	X			
Smith et al. [32]							X
Soe et al. [72]							X
Soriano-Gonzalez et al. [58]	X						
Sotirelis et al. [89]							X
Steenmans et al. [59]			X				
Šulyová and Vodák [90]				X			
Tan et al. [91]			X				
Tomàs [60]			X				
Valencia-Arias et al. [76]							X
Vardopoulos et al. [61]							X
Wang et al. [28]							X
Wey and Peng [92]		X				X	
Wirtz et al. [93]							X
Woods [25]				X			
Yoo [62]			X				
Zaman and Hertweck [73]							X
Zambrano-Prado et al. [63]		X					
Zygiaris [33]							X

Mob.: Mobility; Env.: Environment; Gov.: Governance; Peo.: People; Liv.: Living; Eco.: Economy; Multi.; Multidimensional.

Smart Mobility

Transportation plays a crucial role in urban sustainability due to its significant contribution to GHG emissions, air pollution, and noise [94]. Smart mobility encompasses the integration of ICT infrastructure and the development of efficient transportation systems that are sustainable, safe, and interconnected [11,13,54]. This review indicates that the four cities are dedicated to promoting smarter and more sustainable mobility solutions.

In Barcelona, the city has implemented data-driven technologies for mobility, such as a GPS monitoring system to track public transportation and a smart traffic light system that prioritizes public transportation [40,61]. The city's public transportation system was designed on an orthogonal grid, strategically placing bus stops to facilitate connections between buses, trams, metro, trains, and bicycles. In addition, the bus fleet utilizes hybrid vehicles to minimize emissions, and bus stops provide real-time waiting information and USB ports. The city has implemented a sensor-based and app-enabled free car parking system, reducing the time spent searching for parking spots. The city has invested in expanding and enhancing its cycling path network, and promoted various initiatives to promote cycling, including a bicycle-sharing system with 6000 bicycles, strategically located near transportation hubs and parking areas [40,58,61]. Approximately 33% of the city's technological solutions are dedicated to mobility [35], including popular apps like Trànsit for real-time traffic updates and Bicing for bike sharing [40]. Some of the reviewed documents are specifically focused on enhancing urban mobility in the city [38,46,51].

In Helsinki, Nicolas et al. [13] showed that the SC strategy prioritizes smart mobility to mitigate the adverse environmental effects of motorized transportation. This is further supported by Mora et al. [35], who reported that 43% of Helsinki's technological solutions are dedicated to mobility. These initiatives primarily aim to combat climate change and enhance energy efficiency in transportation. The living lab Forum Virium has played a proactive role in Helsinki's smart mobility initiatives, particularly in achieving low/neutral carbon energy and developing advanced vehicle technologies and services such as electric-assisted vehicles (EVs), autonomous vehicles, robot buses, and drone transportation, among others [26]. One selected study [68] focuses on this domain, establishing an ecosystem for electric vehicle charging stations in Helsinki to facilitate the seamless integration of this infrastructure.

In the case of Medellin, this review highlights the city's commitment to leveraging ICTs to enhance urban mobility and public transportation [32]. This effort includes initiatives to connect hillside and socially marginalized neighborhoods to the city center through escalators and a Metrocable system, aimed at reducing travel time, alleviating traffic congestion, and lowering emissions [74]. Medellin is also enhancing transportation integration by combining metro, buses, trams, and bike-sharing (EnCicla) to make public transportation more sustainable and accessible. The city has installed intelligent traffic light sensors and monitoring systems to optimize traffic flow and reduce congestion [32].

In Singapore, the most developed smart services are in intelligent transportation systems, positioning the city as a leader in smart mobility [28,79]. The Singaporean transportation system is based on three pillars: a compact urban environment with integrated transit, and restrictions on private vehicles [79]. Over the years, policies have focused on integrating land use and transportation planning to minimize travel demand and optimize the use of limited space [26,52,83]. The government has developed various incentives to discourage personal vehicle use, such as an electronic road pricing scheme and high tax rates for new cars [11,52]. The goal is to ensure that 70% of all journeys in the city are made by public transportation [56]. A smart card is available for various modes, collecting travel data that can be used to improve public transportation services [56]. Enhanced technology is in place to ensure the safety of vulnerable road users, including electronic devices that extend pedestrian crossing times and alert drivers to the presence of pedestrians at night [11,79]. Singapore has also adopted a hands-off approach to regulating disruptive transportation technologies and ridesharing [82], which has enabled the city to benefit

from these innovations. The city has conducted various trials with autonomous vehicles, including self-driving cars, autonomous shuttle buses, and driverless trucks [26,86].

Smart Environment

Smart environment is a domain closely linked with urban sustainability [43,44], encompassing issues such as natural conditions, urban green spaces, environmental protection, and biodiversity [26,43]. It also includes actions to monitor and reduce GHG emissions [39], air and noise pollution [89,93], and promote sustainable resource management through efficient use of energy and water [10,11,13,39,43,44,89], along with effective waste management practices [10,44,89,93]. Additionally, policies aimed at mitigating climate change impacts are also integral to this domain [10]. This review demonstrates that all four cities have implemented various measures to advance smart environmental practices.

In Barcelona, various smart environment initiatives related to energy efficiency, air quality, water, and waste management have been adopted [34,35]. The city has made significant investments in implementing smart grids and advanced metering infrastructure, such as smart meters, sensor networks, automated control systems, and cyber–physical systems. These technologies optimize energy distribution and consumption in real time [39]. One of the most innovative energy-efficient projects is the 22@ district, which utilizes centralized energy sources from municipal waste incineration to provide heating and cooling to buildings [10]. The city aims to reduce GHG emissions by 40% by 2030 (compared with 2005) and achieve energy self-sufficiency. To meet these goals, Barcelona launched a program to promote solar energy generation [39]. In waste management, the city has installed bin sensors to monitor fill levels and optimize collection routes, reducing both collection frequency and related emissions [43]. Barcelona also maintains a network of approximately 1800 sensors (Sentilo) that measure real-time environmental indicators such as air quality, humidity, and temperature [10]. In terms of climate change, the city faces challenges such as urban flooding, heat waves, water scarcity, and coastal erosion. The city has increased urban green infrastructure, including parks and green corridors, to mitigate these threats [10]. Additionally, infrastructure development is underway to manage stormwater and reduce flood risks, involving the establishment of a network of stormwater tanks [10].

The city of Helsinki is pursuing sustainable urban development through smart environment initiatives aligned with the UN Sustainable Development Goals [73]. Helsinki has set ambitious goals to reduce its climate emissions with the City Strategy 2017–2021, aiming for carbon neutrality by 2035 through an 80% reduction in GHG emissions [66]. The city launched Climate Watch, an online tool enabling residents to monitor Helsinki's progress toward carbon neutrality [26]. Additionally, the Climate Street project [64], involving businesses, citizens, and public agencies, aims to collectively reduce GHG emissions and energy consumption to enhance climate change adaptation policies. One of the most intriguing smart environment initiatives is linked to the Kalasatama district project. According to Härkönen et al. [66], the goal is to transform Kalasatama into an energy-efficient neighborhood by implementing solutions that enhance energy savings and increase renewable energy utilization through home automation in energy management. The plan includes replicating this energy model across other parts of Helsinki.

Regarding Medellin, the reviewed documents indicate that the city has implemented several initiatives in the environmental sector, which are primarily in the stages of development and systematization [32]. These initiatives encompass projects and tools aimed at monitoring various environmental factors such as air quality and climate change. For example, the SIATA platform is an early warning system designed to monitor and respond to environmental and climatic conditions, continuously monitoring various environmental parameters. The real-time data provided by SIATA can support decision-making processes for urban planning and emergency response [32]. According to Valencia-Arias et al. [76], critical challenges for sustainable development in Medellin include sustainability education

and raising environmental awareness, as environmental sustainability depends not only on political decisions but also on individual behavior.

Regarding Singapore, the city is committed to branding itself as the leading livable and sustainable city [11]. Singapore's sustainable development strategy is bolstered by initiatives like the Singapore Green Plan, considered a pioneering document in biophilic urbanism. This plan focuses on integrating nature into the built environment [56,80], promoting features such as green façades, roofs, corridors, and urban green spaces like Gardens by the Bay [11,43]. The city also has a climate plan aimed at reducing GHG emissions by 36% from 2005 levels by 2030, focusing on energy efficiency and the adoption of low-carbon technologies [88]. Energy consumption has been reduced by 20% through the implementation of solar energy, low-power lighting, and efficient home management systems [43]. During this century, the proportion of electricity generated from natural gas has increased from 19% to 79%, resulting in reduced CO_2 emissions [56]. Singapore aims to have 50% of its electricity demand from renewable sources by 2065 [56]. In terms of water efficiency, Singapore has developed a desalination plant and a water recycling scheme to fulfill up to 30% of the city's water needs [56]. Additionally, Singapore aims to achieve a 70% recycling rate by 2030 [56]. The city has also implemented a smart waste management program that provides information on the content and location of bins, enabling the optimization of waste collection routes [28]. Singapore is also committed to greening its built infrastructure, and around 1650 buildings have been made environmentally friendly, with plans for 80% of buildings to meet sustainable standards by 2030 [11]. In terms of climate resilience, Singapore has implemented flood-control projects [88]. All these initiatives have earned Singapore broad recognition as one of the world's leading SCs in environmental performance [56,92].

Smart Governance

Smart governance is also defined as a critical SC dimension [74,86]. Smart governance involves the use of digital technologies and data-driven approaches to enhance the efficiency, transparency, and responsiveness of government services, as well as to increase citizen participation in decision-making [11,50,74]. This literature review reveals that the four cities have implemented various initiatives to make their governance smarter.

In Barcelona, the SC strategy has been structured around collaboration among government, industry, academia, and citizens [34,35]. In 2016, the smart-citizen policy framework was significantly enhanced with the publication of the document "Barcelona Ciutat Digital: A Roadmap Toward Technological Sovereignty" [42]. This new smart-citizen policy was implemented using various ICT tools, such as the platform Decidim and the app Ethics and Good Governance Mailbox, which enable citizens to participate in decision-making and report mismanagement practices to the municipality, respectively [42,44]. There are also non-digital initiatives focused on fostering smart governance, such as (i) participatory budgeting experiences [45]; (ii) the Cibernarium, a training program to increase professionals' and citizens' knowledge and skills in using digital devices; (iii) the Smart City Expo World Congress, a leading global platform for experts working in the field of SC development; (iv) smart education programs to introduce ICT-driven urban innovation and smartness to children through practical activities; and (v) the organization of hackathons and competitions to actively involve civil society in the SC domain [35]. Barcelona's SC development strategy includes more than 100 collaborative projects spanning solutions and applications in domains such as mobility, air quality, energy, water, healthcare, education, and e-government, among others [34,41]. Comparative studies show that Barcelona has more participatory public policies than cities like Singapore [43].

Helsinki is also described in the literature as a model city in terms of open governance and citizen empowerment [13]. The city is actively committed to promoting openness and citizen participation in developing solutions to shape the SC vision through a bottom-up approach [26,64]. Living labs have played a pivotal role in such a strategy. The living lab Forum Virium has played a key role in developing needs-based and internationally

competitive digital services in collaboration with private businesses, public organizations, and citizens [64]. The ultimate goal is to make Helsinki the most functional SC in the world [26]. Forum Virium has supported more than 80 projects for co-created SC solutions, involving 750 companies and 60 partner cities [26]. Smart governance has been promoted through various platforms and initiatives such as Helsinki Region Infoshare (HRI), an open-data service available to all; Open Ahjo, an app providing access to the city's decision-making material; Open Helsinki Hack-at-Home, a platform encouraging the use of open data; and Helsinki Loves Developers, a regular meeting of app developers [35,64]. Helsinki was also involved in the Six City Strategy (6Aika), a joint sustainable urban initiative by the six largest Finnish cities [31].

Medellin has been promoting community labs to encourage citizens to use and benefit from ICTs [59]. The Medellin Innovation District and Ruta N are among the entities most actively engaged in promoting collaboration between businesses, academia, citizens, and government to drive innovation, economic development, and entrepreneurship [76]. To improve transparency and encourage citizen participation in decision-making, Medellin has been adopting various initiatives such as participatory budgeting, digital government services, participation in national and international city networks, and the publication of data about specific urban indicators [59]. One example is the Open Data Council, a platform to collect and make open governmental data [32]. However, Smith et al. [32] argued that the adoption of smart governance in Medellin has been constrained by issues such as the lack of a culture of data collection and management, challenges in data disaggregation, concerns about losing power, and participatory processes that often focus narrowly on specific urban issues like flooding and landslides.

According to this review, Singapore is reported as an open-source society renowned for its levels of transparency, openness, and trust, with a particular focus on smart governance [79]. The Smart Nation living lab itself acts as a comprehensive database accessed through an extensive service network, offering a variety of services [79,93]. Around 98% of electronic services, primarily in healthcare, mobility, and public administration, are available online, including 385 e-services and e-citizen portals [43,80], which position Singapore as an "information city" [79]. Various public platforms disseminate data, such as OneMap and the Urban Redevelopment Authority (URA) Map portal [93], while others like REACH (Reaching Everyone for Active Citizenry@Home) and Singapore Together are designed for collecting citizen opinions and shaping public policies [43]. In terms of collaboration, the Singapore Government and the private sector are working together to enhance and position Singapore as a more attractive and competitive destination [11]. In Singapore, living labs like Smart Nation have played a crucial role in promoting smart governance and fostering collaboration among global companies, high-tech startups, and public institutions [84]. Lastly, the city is engaged in several transnational development projects, including the ASEAN Smart Cities Network (ASCN), which Singapore promoted to enhance environmental sustainability and strengthen regional collaboration [12,91].

Smart People

This domain primarily focuses on the skillset and education level of the city's human capital [11,89], and on social inclusion and equality [13,36] in aspects such as ethnic diversity, cosmopolitanism, openness, flexibility, creativity, and public participation [11,13,34,89]. Smart people are considered crucial because SC initiatives often demand innovative, creative, and collaborative solutions [89]. In general, highly educated individuals drive the development of SCs [34,91] but it has been shown that smart solutions can create new forms of social division and exclusion [25,36]. For these reasons, inclusiveness has become a central element in SC policies, focusing on reducing disparities between groups, such as in education and wealth, and addressing social barriers, particularly in learning and participation processes [36].

Barcelona is known for its emphasis on citizen participation, digital inclusion, and education within its SC initiatives. These include, for example, smart education programs

for primary and secondary schools to introduce the concept of SCs and innovation to young students and help them develop smart solutions [35,40], and courses, seminars, training sessions, competitions, and hackathons to enhance digital literacy among professionals and citizens, with the Cibernàrium serving as the city's main technological training facility [33,35]. In terms of public participation, the Decidim platform has engaged 120,000 participants, generated 27,000 citizen proposals, and 3500 physical meetings as part of over 50 participatory processes [95]. As noted by Calzada in 2018 [42], many of these citizen proposals (70%) were successfully implemented as public policies across a wide range of initiatives. Barcelona has been particularly active in fostering inclusiveness and citizen empowerment, providing ICT tools to assist elderly people in their everyday lives [35,49,53]. These efforts helped Barcelona in performing better than other cities in this domain including London [40], Singapore, New York, and Istanbul [43].

Helsinki emphasizes smart people through its focus on citizen engagement, education, innovation, and inclusiveness [64]. Helsinki is regarded as a model for citizen empowerment and open governance, especially with its bottom-up approach that involves living labs in designing citizen-centric services [13]. Through companies like Forum Virium, Helsinki has fostered a collaborative and experimental organizational culture aimed at democratizing innovation and enhancing public participation [64]. Consequently, Helsinki consistently ranks better than other SCs, such as Singapore and London, in promoting bottom-up approaches [26] and needs fewer communication initiatives than other cities due to the already high level of public participation achieved in the city [13]. Helsinki is placing a strong emphasis on equitable access to digital services and infrastructure, ensuring that technological progress does not exclude any segment of the population. Within the Kalasatama project, the city is also implementing a pilot age-friendly housing community, which is planned to be rolled out to the rest of the district.

Medellin has been addressing historical inequalities through the integration of social innovation into urban planning, making sure that SC benefits reach low-income and marginalized communities. These include social urbanism initiatives to connect peripheral neighborhoods to the city center and to provide citizens with educational and cultural facilities, like public libraries, to enhance their social inclusion and digital skills [32]. However, the city still has considerable socioeconomic barriers that hinder citizens from less privileged groups from participating in the development of SC initiatives [32]. For these social groups, the most significant barriers include less accessibility and usability of technologies, technological illiteracy, and digital solutions that often overlook their needs [76]. Within this domain, Smith et al. [32] argued that a redefinition of SC approaches to effectively respond to the needs of Medellin's population and foster social inclusion is urgently needed. Reinforcing the investment in ICT infrastructure and reducing technological illiteracy is critical to achieving that goal [76].

Singapore's focus has been in creating a tech-empowered society and the city has invested significantly in integrating ICT into its education system [80]. However, several challenges restrict the effectiveness of smart people initiatives, including a governmental top-down approach, an aging society, and the complexities of a mixed-race population. First, the Smart Nation strategies have been based on a top-down approach controlled by the government [26,43,84]. The strategy encourages citizens to participate in envisioned SC initiatives, but does not allow them to truly shape these initiatives [26]. The goal has been to prioritize the interests of the country over those of its citizens [84]. Second, the Smart Nation plan does not adequately consider the aging process and the diverse needs of the elderly population in the city [25,78]. Some seniors in Singapore are less fluent in English, have lower educational backgrounds, and possess less experience with technology, which diminishes their motivation to participate in SC initiatives. Third, Singapore has a mixed-race population with significant cultural diversity, which poses challenges in including their vision into SC initiatives and in mobilizing their public participation [11]. Thus, despite extensive ICT coverage and the high digitalization of public services that are

accessible to all citizens, Singapore performs worse than other cities in issues related with public participation and social inclusion [43,84].

Smart Living

Smart living is an SC domain focused on enhancing citizens' quality of life by providing more efficient, comfortable, and satisfying living conditions [11,13,27]. This domain encompasses various components such as housing quality, healthcare, education, security, social cohesion, culture, and recreation [11,13,36,89]. Enhancing citizens' quality of life is a main goal of SCs, making smart living a fundamental aspect of this concept [13,70]. As noted by Bibri and Krogstie [40], advancements in ICT across other SC domains, such as mobility and governance, also contribute to improving overall quality of life.

Based on the concept of being a city for its people, Barcelona's SC goal aims to enhance well-being and quality of life through a wide array of applied technological solutions [39,43]. To achieve this, the city has made significant investments in its ICT infrastructure, which includes an extensive IoT sensor network that collects data across various sectors impacting quality of life, such as energy, environment, transportation, health, and security [40]. A SC model involving active public participation was developed to analyze the extensive data collected and efficiently manage both public and private services and their access. The Municipal Institute of Information Technology and the municipal company 22@ Barcelona have spearheaded various projects, such as smart parking and bin sensors, aimed at creating a sustainable city with an enhanced quality of life [39,43,61]. Barcelona also adopted non-digital smart living initiatives including incentive programs for urban housing renewal [52,60] and efforts to reduce social inequalities and exclusion [10,60]. For these reasons, Barcelona ranks well among the top European cities for quality of life and smart living [43,52].

The literature also confirms that Helsinki is a leading city in smart living, with numerous urban initiatives aimed at improving residents' quality of life through technology and sustainable practices. For example, preserving the natural environment is a key aspect of enhancing the well-being of its inhabitants [13]. The Smart Kalasatama project, in particular, has tested and implemented various sustainable smart solutions. This includes renewable and energy efficiency solutions to make the neighborhood self-sufficient, as well as the adoption of building automation in commercial buildings and apartments for energy-related services and electric demand management [66]. Additionally, mobile health platforms like Kalasatama Wellbeing allow citizens to record their diets and receive immediate dietary advice [31]. Another example is the provision of QR codes, which enable visitors to access free guided tours of Helsinki's sights via their smartphones [35].

In Medellin, the reviewed documents focused on initiatives taken to mitigate spatial segregation, social inequalities, and urban violence. As described by Smith et al. [32], the first initiatives aimed to address the spatial segregation and urban violence that characterized the city in the early 1990s. This was achieved through a range of social urbanism measures designed to improve poor neighborhoods, such as the PRIMED program, and connect the peripheral hillside neighborhoods to the city center through the Metrocable system. Community labs and projects, such as Makaia, have been used to build partnerships and relationships oriented toward social and economic development [32,59]. However, these improvements have been limited, and socio-spatial segregation between the center and the periphery remains, partly due to accelerated and unplanned urban growth. According to Valencia-Arias et al. [76], the lack of security and access to essential services such as healthcare and education are among the most critical urban issues faced by the city in this domain.

Singapore's SC strategy has been developed with the ultimate goal of enhancing the quality of life for all citizens and developing as a sustainable city [11,56]. As mentioned before, Singapore provides a wide variety of services to its citizens and 95% of homes and businesses have ultra-fast Internet connectivity [11]. More than 100 mobile services are available to citizens, including those from government agencies, public entities, and

private sectors. As shown by Wirtz et al. [93], smart social services encompass a diversity of healthcare, education, and cultural services, with healthcare being the most representative and analyzed in the literature. According to Iryna et al. [83], the Singaporean healthcare system is highly digitized, for example, practitioners routinely engage with patients remotely and the platform MyDoc provides various health functions such as virtual consultations. Assistance for lonely patients is possible with AI-based chatbots. The integrated functional payment system, including platforms like the EZ-Link card and the Singapore Quick Response Code (SGQR), is also highlighted in some publications for facilitating seamless transactions across various services [43,84]. The mobile app "SingPass" is noted for allowing easy individual access for transactions with the government [77,93].

Smart Economy

Smart economy is identified as a key factor in SC development, focusing on economic competitiveness, productivity, and labor market flexibility, emphasizing integration and transformation within local and national markets [44]. The concept involves the use of digital technologies and human capital, such as skills, creativity, and knowledge, to create competitive products and services based on efficiency and sustainability [11,43]. Additionally, a smart economy may promote a green economy by fostering companies that encourage renewable energy and enhance energy efficiency.

The reviewed documents show that Barcelona has implemented several initiatives under its SC strategy to boost economic progress, focusing on innovation, entrepreneurship, and sustainable economic growth. The role of project 22@Barcelona is highlighted for attracting qualified professionals and knowledge-based businesses linked to the new economy, such as media, design, ICT, and energy [41,52,53]. These conditions have transformed the city into a highly attractive and sustainable business environment [10,44,61]. Noori et al. [50] also emphasized the role of Barcelona Activa, a local development agency focused on promoting entrepreneurship and offering support to companies and startups. The organization of the Smart City Expo World Congress since 2011 is also noted for positioning Barcelona as a leader in SC innovation, attracting global businesses, investors, software companies, and equipment and utility providers [35,60].

Like Barcelona, Helsinki has implemented several initiatives to promote a smart economy to make the city more competitive nationally and globally [73]. The literature indicates that Forum Virium has been committed to creating new businesses, improving services, establishing links to international markets, attracting foreign investment and businesses [64], organizing innovation competitions, and funding [73]. The Smart Kalasatama project is noted in various documents for its role in attracting companies, particularly those focused on sustainable businesses that develop and offer energy savings, and demand management services for city residents [64,66]. The study conducted by Zaman and Hertweck [73] indicated that the city's smart growth heavily relies on Kalasatama for testing solutions to urban problems, including public transportation and energy use. The city's focus on promoting smart economy initiatives is highlighted in various documents. For instance, Nicolas et al. [13] noted that 30% of the interventions and announcements in Helsinki are related to smart economy. This emphasis has significantly contributed to Helsinki's competitive edge, as evidenced by its high rankings in entrepreneurship, startups, and high technology [59].

In the case of Medellin, smart economy issues are explored in only two of the returned documents [32,76]. In their analysis of key aspects of implementing SC initiatives in Medellin, Smith et al. [32] identified socioeconomic inequalities and the lack of technological skills as the most critical challenges for boosting a smart economy. Similarly, Valencia-Arias et al. [76] identified three main socioeconomic challenges for the city: the prevalence of informal labor, the need to redefine industrial and productive styles, and the financial resources required to implement the necessary changes. Recognizing these issues, the city initiated an economic transition process centered on service sectors, with a focus on strategic clusters such as digital businesses, sustainable habitat, health, business tourism, and the

reinforcement of ICT infrastructure [32]. Initially driven by the public sector, this process has evolved to include public–private initiatives, exemplified by programs like Medellin Digital City, aimed at enhancing the city's technological infrastructure. Additionally, the innovation and business center Ruta N is noted for its role in fostering entrepreneurship, supporting startups, and attracting international companies [32,76].

Finally, the efforts undertaken in Singapore to create a smart economy are well-documented in the reviewed literature. According to Della Corte et al. [11], Singapore's masterplan emphasizes the use of ICT to enhance economic competitiveness by fostering creativity and enabling innovation among businesses. In Singapore, the private and public sectors have been collaborating to make the city an attractive global living lab destination for smart technologies and improve the industry using ICT [11,84,91]. The government has been actively supporting its living labs, through which several global and national companies, high-tech startups, and Singaporean institutions are collaborating to find innovative technological solutions for various business sectors, including healthcare, autonomous vehicles, security, and tourism, among others [84]. These collaborative initiatives have allowed the city to continuously seek and seize business opportunities and explore the technologies to meet new market needs [11]. In addition, the government launched initiatives such as Build Amazing Startups Here (BASH), an all-in-one startup facility designed to attract and support tech startups [84]. Within the context of the ASCN, Singapore has encouraged the creation of partnerships and positioned itself as a leading global business and technology hub [91]. As a result of these efforts, Singapore has achieved impressive milestones: it has attracted 7000 international companies, boasts one of the highest per capita income levels in the world [56], is one of the most competitive cities in the global economy [84], consistently ranks high in SC rankings [77], and is positioned to build a smart nation ready for the Fourth Industrial Revolution [84].

4. Discussion

This review of smart sustainable practices across Barcelona, Helsinki, Medellin, and Singapore has highlighted significant advancements and persistent challenges within the six SC domains. This discussion critically evaluates the initiatives undertaken, focusing on key insights and identifying areas for improvement in fostering more sustainable urban planning through SC initiatives.

The literature review showed that the emphasis in the four SCs has been on ICT solutions, along with good governance, environment, economic development, and social inclusion as the primary concerns. As shown in Table 3, each city has developed strategies tailored to its local context, yet common themes such as the integration of technology, community engagement, and effective networking have emerged as critical components in enhancing sustainable urban development. Therefore, instead of representing uniformity across the four studied cities, the concept of a SC should be understood as one that interacts with and adapts to local and national contexts. Although there is some overlap in areas like mobility and environmental sustainability, this review revealed that each city has tailored its SC approach to reflect its unique priorities and specific contexts. For example, Singapore has invested heavily in ICT and enhancing the city's global competitiveness through a top-down approach. Medellin has concentrated on reducing urban and social inequalities through transportation, housing, and education initiatives aimed at mitigating socioeconomic disparities. Helsinki emphasizes open data, digital public services, and sustainability, with the Kalasatama district serving as a living lab for testing smart energy solutions, urban mobility, and sustainable living practices. Meanwhile, Barcelona has focused on promoting citizen-centric governance, using digital technologies to improve public services and enhance public participation in urban development through platforms like Decidim.

Table 3. Main smart city initiatives adopted in the four cities.

City	Mobility	Environment	Governance	People	Living	Economy
Barcelona	- Data-driven public transport; - Smart traffic; - Cycling infrastructure.	- Energy efficiency; - Smart grids; - Climate resilience.	- Bottom-up; - Citizen participation; - Digital platforms.	- Educational programs; - Cultural initiatives.	- Digital inclusion; - Public health.	- Innovation hubs; - Support to startups.
Helsinki	- Sustainable transportation; - Electric vehicle infrastructure.	- Carbon neutrality; - Climate monitoring.	- Bottom-up; - Open data; - Citizen empowerment.	- Education on digital literacy; - Living labs and innovation.	- Sustainable building solutions; - Mobile health.	- Smart Kalasatama; - Support for green businesses.
Medellin	- Metrocable; - Public transportation modernization.	- Urban regeneration; - Green corridors.	- Bottom-up; - Social inclusion; - Community-driven projects.	- Citizen engagement; - Tech access inequalities.	- Social urbanism and inclusion.	- Support for local businesses.
Singapore	- Smart traffic; - Autonomous vehicles.	- Biophilic urbanism; - Climate resilience.	- Top-down; - Electronic services; - Global projects.	- Tech education; - Senior and racial inequalities.	- Smart homes; - Digital health; - Fast Internet.	- High-tech industries; - Global business hub.

A key finding of this review is the uneven focus on specific SC domains. Smart governance and smart environment are the most studied dimensions, highlighting an emphasis on governance efficiency and environmental sustainability in the four cities. Conversely, smart economy, smart living, and smart people received significantly less attention, despite their importance in holistic urban sustainability. This trend aligns with prior studies that indicate a lack of emphasis on societal aspects within SCs [22,36]. The limited exploration of these dimensions underscores the need for greater attention to societal factors, particularly economic sustainability and social well-being, which have often been overshadowed by technological and environmental concerns [45].

Regarding the lessons learned, the concept of "smart", particularly in Barcelona, Helsinki, and Singapore, is closely linked to using ICT to enhance urban operations and sustainable practices through the extensive data generated. However, this presents two main challenges. First, ICT-driven initiatives often prioritize economic and competitive aspects over addressing social needs [45,57]. Second, the mere availability of digital technologies does not ensure that all individuals can think or act smartly. For instance, the review found that in Singapore, certain social groups—specifically the elderly and some ethnic minorities—are less included in SC initiatives due to lower educational levels and tech skills [79]. The exclusion of these vulnerable populations can create new forms of socio-technical division and exclusion [25], resulting in SC initiatives disconnected from social and cultural contexts, potentially leading to solutions that are technologically advanced but socially inequitable and unsustainable. To address these challenges, social

needs must be integrated into the planning and implementation of ICT-driven initiatives, ensuring that economic and competitive priorities do not overshadow inclusivity. Further, as demonstrated in Medellin, cities must develop inclusive digital literacy programs and foster public–private partnerships to enhance ICT and R&D investments, particularly in resource-limited areas [35].

Governance also emerged as a critical domain in the reviewed SC strategies. In the four cities, ICT solutions assist planning authorities in defining and monitoring public policies, enhancing transparency, local democracy, and public participation. Living labs and innovation centers play a pivotal role in engaging citizens and stakeholders in developing e-services for all, while online platforms and apps are essential for disseminating data and facilitating interactions with residents. However, in terms of governance approach, this review indicated a divergence, with Barcelona, Helsinki, and Medellin adopting a bottom-up strategy [13,26], whereas Singapore employs a more top-down, government-controlled approach [26,43,84]. Bottom-up approaches are more effective in fostering community engagement, empowering local voices, and promoting social and urban inclusion, while top-down strategies tend to be less responsive to the population's needs and public interest [35,57,64]. This review has confirmed that Barcelona, committed to citizen-centric governance, demonstrates higher levels of public participation in SC initiatives compared with Singapore [43]. Therefore, a balanced governance model that combines leadership with community-driven initiatives could be more effective in ensuring the success of SC strategies [35,64].

Confirming previous studies [26,76], environmental sustainability also appeared as a key dimension of SC strategies in the four cities. Advanced ICT and big data are utilized to address issues such as GHG emissions, air and noise pollution, energy and water consumption, and waste management. However, this review suggests that while ICT advancements are well-documented, the environmental benefits of these technologies are less explored. In the environmental dimension, some authors have argued that ICT solutions have been used for promotional purposes and for political motivations to face complex urban challenges, rather than to evaluate their benefits and the actions required to increase urban resilience and livability alongside urban smartness [69,76]. This indicates a pressing need for more comprehensive evaluations to understand the extent to which SCs genuinely contribute to environmental sustainability.

Building on the insights gained from this review, it is essential to examine the smart sustainable urban practices adopted in the four cities. The notion of smart sustainable cities represents a relatively new holistic paradigm of urbanism, emphasizing sustainable urban development supported by ICT [10,40]. Sustainable urban development goals are inherently part of several initiatives described in the reviewed documents. Cities like Barcelona and Helsinki are strongly committed to becoming a showcase for sustainable urban development [39]. But out of the 71 papers reviewed, only a few specifically focused on smart and sustainable urban development [3,37,39,61,65,70]. In the revised literature, the integration of sustainable development goals into SC strategies is rarely explored comprehensively. The searched documents do not effectively demonstrate best practices within a smart sustainable development framework, as the primary focus has been on how ICT solutions address specific issues, such as mobility and environmental concerns, often overlooking broader urban challenges. Although the concept of SCs has been consistently utilized in these four cities and in the literature for over a decade, it remains unclear how effectively they have mitigated or resolved some of the most pressing urban issues. For instance, in Barcelona, SC initiatives have centered on projects like public Wi-Fi and smart sensors for managing public spaces, but these efforts have done little to tackle deeper urban concerns, such as housing affordability and wage inequality. Similarly, Helsinki has made progress in open data and digital public services; however, challenges persist in bridging the digital divide and ensuring equitable access to these innovations for all citizens. In Medellin, despite significant advancements in urban mobility solutions like the Metrocable system, issues related to social equity and poverty reduction remain unresolved. Lastly,

Singapore has adopted a top-down approach to SC development, heavily investing in ICT, yet these initiatives have not effectively addressed social inclusiveness, particularly for aging populations and marginalized groups who struggle with digital literacy and access. As observed in Barcelona [58], Helsinki [73], and in other cities like Rio and Tokyo [96,97], urban redevelopment and regeneration projects associated with SC initiatives can enhance the quality of life by improving infrastructure, connectivity, and public services. However, they also contribute to socioeconomic and urban inequalities, including gentrification and the displacement of local communities. It appears that smart urbanism policies often concentrate on specific urban development strategies in which local actors reframe existing targets to unlock funding and resources, rather than addressing the root causes of urban challenges. These findings align with previous studies indicating that smart urbanism frequently lacks a comprehensive consideration of urbanism, prioritizing technological solutions over holistic urban development strategies [29], indicating that urban sustainability has not been a main driver for SCs [23]. To achieve truly smart and sustainable urban development, cities need to transcend a narrow focus on ICT solutions and tackle deeper socioeconomic and urban challenges. Smart urbanism positions society and the urban context as primary parameters in developing digital initiatives. Therefore, there is a need for a more comprehensive understanding of how technology and urbanization intersect in shaping SC approaches and their impacts on contemporary urban life. Holistic approaches that integrate social equity, inclusiveness, and long-term urban planning are essential for ensuring that SC initiatives effectively address the complex challenges cities face today and contribute to improving the quality of life for all citizens.

5. Conclusions

This study offers valuable insights into the implementation of SC initiatives across Barcelona, Helsinki, Medellin, and Singapore, emphasizing the various strategies employed across six domains to integrate sustainable urban practices. Despite notable advancements in governance and environmental management, there remains a concerning gap in how effectively these initiatives engage with broader urban challenges. As observed, while technological solutions have been prioritized, the need for inclusive and holistic practices that address socioeconomic disparities is critical to ensure that smart urbanism truly enhances the quality of life for all citizens. Drawing on the lessons learned from this review, we recommend for future studies to carry out the following:

(i) Develop comprehensive frameworks to assess the performance of smart sustainable cities, namely in addressing socioeconomic disparities and environmental challenges;
(ii) Analyze methods to enhance community involvement and ensure social equity in smart sustainable urban projects, with a focus on the influence of social and cultural factors on public participation and social inclusion;
(iii) Investigate how SC initiatives are successfully translated into urban sustainability practices, with a focus on identifying the challenges and opportunities that influence their effectiveness in real-world applications;
(iv) Provide additional evidence about the benefits of ICT in promoting urban sustainability through quantitative models, indicators, or metrics.

Finally, this review has several limitations that should be acknowledged. First, it focused solely on scientific papers published in English and indexed in two databases (Scopus and Web of Science). Therefore, studies published in other languages, in different repositories, or alternative formats such as conference papers, were not included. Second, the selection of documents was guided by specific search criteria detailed in the methodology, which may have led to the exclusion of other relevant research. Third, due to the large number of papers reviewed, only key findings were highlighted instead of conducting a comprehensive meta-analysis. Lastly, the findings of this study are limited to four cities. Future research could benefit from including additional cities from all five continents to enhance the representativeness of diverse urban contexts and provide a more comprehensive overview of global SC development, particularly comparing developed

and developing countries. Despite these limitations, this study significantly contributes to clarifying the concept of smart sustainable cities, improving the design and implementation of sustainable urban planning practices, and promoting more sustainable and livable urban environments.

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