Smart City and Urban Sustainability

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Abstract

Exploring the concepts of smart city and urban sustainability has become a necessity in addressing the complex challenges of modern urbanization. As new technologies emerge, cities around the world are opting to transition to a smart city, but without giving up on sustainability, understanding how these two concepts intertwine is essential to shaping future urban development.

The symbiotic relationship between smart city technologies and urban sustainability goals will be investigated through a cluster analysis based on composite indices: *Smart City Index*, *Happy City Index*, *Quality of Life Index* and *Innovation City Index*. By including cities in distinct clusters, the study reveals varying degrees of integration between technological advances and sustainability practices. The results show that cities can be grouped into specific categories that reflect their success in harmonizing digital technology implementations with sustainability goals, showing that a balanced approach to the two concepts can lead to high living standards and robust sustainability outcomes.

This study is distinguished by introducing an innovative classification framework that provides a different perspective on the interaction between smart cities and sustainability using an analysis based on composite indicators. This framework highlights the diverse strategies adopted by cities despite these challenges, underscoring the need for a balanced urban development strategy. Such an approach promotes not only technological progress but also progress in environmental sustainability and improving the quality of life, thus providing a model for cities that want to adapt to the needs of the current era.

Keywords: Smart city, digital participation, sustainability, inclusive development, IoT, Cluster Analysis.

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Introduction

Smart urbanism and digital participation are two key concepts in the evolution and optimization of contemporary urban spaces, combining technology and the active involvement of citizens to achieve the goals of sustainable and efficient urban development. Smart urbanism is defined as the application of advanced technologies such as the Internet of Things (IoT) and data analytics to manage and optimize urban resources, including transport, energy and public services (Bibri and Krogstie, 2020). This approach results in a connected urban ecosystem where infrastructure interacts synergistically, having a significant impact on the quality of life of residents and environmental sustainability.

Digital participation is an essential pillar in the decision-making process at the urban level. This involves the use of online platforms, mobile applications and social media to facilitate dialog between citizens and authorities, thereby promoting transparency and inclusiveness in the decision-making process. Citizens become active participants in gathering information, providing feedback and developing suggestions for urban projects, thus helping to shape urban planning according to the needs and expectations of local communities (Bouzguenda, Alalouch and Fava, 2019).

The effective integration of smart urbanism and digital participation is an essential step in building cities that provide an inclusive and sustainable living environment (Komninos et al., 2019). This approach not only maximizes the benefits of technology in urban planning, but also strengthens the links between citizens

and decision-makers, promoting effective and accountable urban governance. The synergy between these two concepts represents an essential foundation for the evolution of cities in the context of a constantly changing digital world.

In this context, the present study aims to identify common patterns and trends within smart and sustainable cities, provide a detailed insight into different development strategies, and assess the relationship between technologization and sustainability in smart cities.

Review of the scientific literature

Smart cities strategy increases the quality of life of residents by modernizing urban infrastructure with the help of advanced technologies. Sustainability is a long-term objective that balances environmental, social, and economic aspects in the context of improving urban life. Thus, the development of smart and sustainable cities can lead to the creation of an optimal framework for increasing the quality of urban life, but simultaneously, it can be the answer to the current climate challenges (De Guimarães et al., 2020).

At the same time, the advantages provided by the possibility of educational development and the ease of finding a job are factors that influence urban migration. According to the United Nations (UN), if in 2012 it was estimated that 52.5% of the global population lived in urban areas, ten years later, the share of the urban population increased to approximately 57%. However, the estimated population growth in urban areas to 68% by 2050 will also accentuate the negative consequences of accelerated urbanization: pollution, intensification of carbon emissions, reduction of resources, and, last but most importantly, the accentuation of social inequalities. A solution to overcome these difficulties is the integration of digitization in the transformation of traditional cities into smart and sustainable ones (UN, 2022; United Nations Department of Economic and Social Affairs Population Division, 2022; Intergovernmental Panel on Climate Change (IPCC), 2023).

Acceleration of technological innovations and increasingly pronounced urbanization, together with a growing ecological consciousness, have led to a reassessment of technology as a tool for sustainable development. In the current context, we can consider the merging of the concepts of the sustainable city and the city as a solution to social, economic, and environmental problems. Thus, in 2016, the International Telecommunication Union (ITU) and UN initiatives launched the Sustainable Smart Cities (U4SSC) campaign, which establishes a framework of performance indicators for sustainable smart cities, facilitating the adoption of specific policies toward cities (U4SSC, 2016). This action proposes a set of key performance indicators with the help of which city development can self-assess the achievement following the implementation of new digital technologies in smart and sustainable city development with the aim of meeting the Sustainable Development Goals (SDGs) established by the UN.

Collecting data to better respond to the needs of residents is one of the benefits of sustainable urban development that directly results enhances the quality of life in smart cities. The implementation of new technologies, combined with sustainability policies, optimizes energy consumption, improves water resource management, and creates a safer urban environment. Furthermore, it enhances urban mobility by reducing traffic congestion, promoting public transport, and supporting the use of electric vehicles, thus reducing carbon emissions (De Guimarães et al., 2020).

Starting from the premise that smart cities transform the urban landscape by implementing advanced technologies and IoT solutions – by optimally managing resources and reducing costs by achieving efficient and interconnected urban services – and that sustainable urbanization encourages a balance between economic development, environmental protection and the prosperity of communities, a bibliometric analysis of the specialized literature will be conducted. This review aims to identify, examine and synthesize the trends, methodological approaches and main findings in the field of smart cities and sustainable urbanization, thus providing a comprehensive perspective on the evolution and impact of these initiatives in the current and future urban context. This review will not only provide an in-depth understanding of the current state of research but also guide future directions of study in this vital field.

For a complex approach to specialized literature in the context of this research, the focus will be on the smart city in relation to urban sustainability as a state or condition. Thus, the bibliometric analysis will be conducted on the basis of publications resulting from the search on the Web of Science (WoS) platform for the key phrases "*smart city*" AND "*urban sustainability*". The results showed that of the 164 publications identified in the period 2013-2024, 136 are articles or proceeding Papers. For the accuracy of the results, inclusion and exclusion criteria were used (Radu et al., 2024). Thus, only article-type publications were included in the analysis, and those published in the current year (Jan-Apr 2024) were eliminated. The final

sample comprises 114 articles published between 2013 and 2023, providing a more nuanced picture of how the two concepts fit in the specialized literature (Figure no. ***1***).

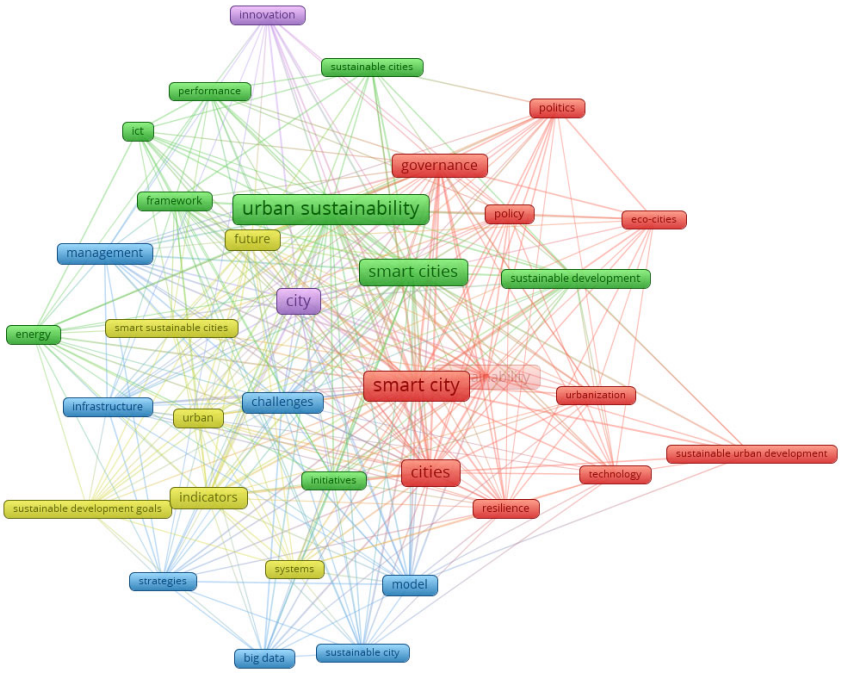

Figure no. 1. Interconnected Network of Smart City and Urban Sustainability Concepts
Source: own processing of authors using VOSviewer

Research methodology

The approach of Ahvenniemi et al. (2017) focused on comparative analysis between assessment systems used for smart cities and those used in the context of urban sustainability. They developed a concise analysis of the evolution of the two methods of quantifying urban performance. One of the objectives proposed to be researched later is the identification of the similarity between the result of the evaluation of a city, with a framework for measuring the performance of a smart city, and that obtained following the application of a sustainability framework (Ahvenniemi et al., 2017).

Starting from this idea, the following research hypotheses are formulated:

- Cities can be grouped into distinct clusters based on their performance in the dimensions of sustainability and implementation of digital technologies. (#1)

- The performance of cities in terms of sustainability and smart technology varies significantly by geographic region. (#2)

Given the multidisciplinary and complex nature of the analysis of smart cities and urban sustainability, adopting a rigorous methodology is critical for analysing the interdependence between technology, governance strategies, and human behaviour. Considered as innovative urban ecosystems, smart cities use technology to improve not only the quality of life but also urban efficiency and environmental sustainability (Appio, Lima and Paroutis, 2019). In this context, the current research aims to explore how composite indicators can reflect and influence urban sustainability performance within smart cities.

The inclusion of composite indicators in the analysis is based on their ability to provide a comprehensive picture of smart cities' performance and progress toward sustainability goals (Akande et al., 2019). Simultaneously, the use of statistical methods of multivariate analysis will allow the identification of models and dependencies between different indicators to subsequently quantify their impact on urban sustainability.

Thus, to respond to the established objectives, Cluster Analysis (CA) will be used, which will allow the grouping of cities according to similarities, starting from their sustainability performance, based on similarities in the use of smart technologies, resource management, or applied sustainability policies. The

analysis will be performed with Visual Studio Code (Version: 1.88.0), and to create the dendrogram, in order to minimize the variance within each cluster, the Ward method was used (Strauss and Von Maltitz, 2017). In the context of smart cities and urban sustainability, the application of the Ward method suggests that each cluster formed on the dendrogram groups together cities with similar profiles in terms of these indices, thus indicating a similar approach to innovation and sustainability, which can facilitate the interpretation and comparison of strategies for different urban areas.

Based on the results obtained, the leading cities in terms of urban sustainability and innovation within smart cities will be identified, as well as the possibility that they present good practices that contribute most effectively to the achievement of the objectives of urban sustainability and innovation.

The indicators integrated in the multivariate analysis, considered necessary in the study of the characteristics of smart cities, are presented in Table 1.

Table 1. Indicators

Indicator	Description	Component	Year	Data source
Smart City Index	The integration of IoT sensors into urban infrastructure, along with other new technologies, is shaping the future of data and automation in everyday urban life, transforming smart cities into a citizen-centric experience. The use of open data sets is determined, based on the methodology used by the **IMD** to build the *Smart City Index**	Smart Mobility Smart Environment Smart Government Smart Economy Smart People Smart Living	2020	https://www.kaggle.com/datasets/mag-da-monteiro/smart-cities-index-datasets
Quality of Life Index	It represents a measure that reflects the general well-being in a certain place (city/country), by evaluating the various aspects that contribute to the well-being of residents (a higher value of the index indicates a better quality of life).	Purchasing Power Index Safety Index Health Care Index Cost of Living Index Property Price to Income Ratio Traffic Commute Time Index Pollution Index Climate Index	2023	https://www.numbeo.com/quality-of-life/rankings.jsp?title=2023
Happy City Index	It assesses the well-being of a city's residents, incorporating various factors that contribute to happiness and well-being. The aim is to understand how urban environments influence the happiness of its inhabitants and lead to the optimization of policies to improve the quality of urban life.	Citizens Governance Environment Economy Mobility	2023	https://happy-city-index.com/
Innovation City Index	It showcases the world's most innovative cities, ranking them based on a comprehensive set of 162 indicators. This assessment highlights cities' prerequisites for innovation, including factors such as digital transformation, startups, economic development and sustainability. It is a tool for evaluating and improving the innovation ecosystems of cities.	Cultural Assets Human Infrastructure Networked Markets	2023	https://innovation-cities.com/

Note The Leap Data team utilized globally-recognized indices (formalized for the evaluation of Smart City initiatives), and developed a data model to interpret how Calgary & Edmonton stand in relation to Global Leaders of Smart City activities. The indices utilized to create these insights were developed exclusively from Open Datasets.*

Source: own processing of authors

Results and discussion

Based on the results of the cluster analysis, the dendrogram shown in Figure no. ***2*** illustrates how these cities can be grouped together based on their measures of sustainability and innovation, thus providing insight into how different cities compare and collaborate in the global context of smart cities and urban sustainability.

Using data on cities around the world for which data are available on the indicators included in the analysis, Smart City Index, Happy City Index, Quality of Life Index and Innovation City Index, statements can be made for each cluster in the context of smart cities and sustainable urbanism:

• *Green cluster:* includes cities located in Europe and Asia, illustrating a mix of Western and Eastern European cities, as well as major cities in the Middle East and East Asia. This reflects the cultural and economic diversity within the cluster and the wide potential for knowledge exchange and innovative practices between these regions. Seoul and Taipei are leaders in information and communication technology (ICT), advancing the adoption of technology in all aspects of urban life. The cities of Lisbon, Prague, Taipei, and Tallinn are known for their rapid adoption of digital technologies and smart city initiatives that improve municipal services and citizen participation. In the context of sustainable urbanism, this cluster could represent cities that have implemented green technologies or sustainability policies in a similar way (Akande et al., 2019; Walentek, 2021).

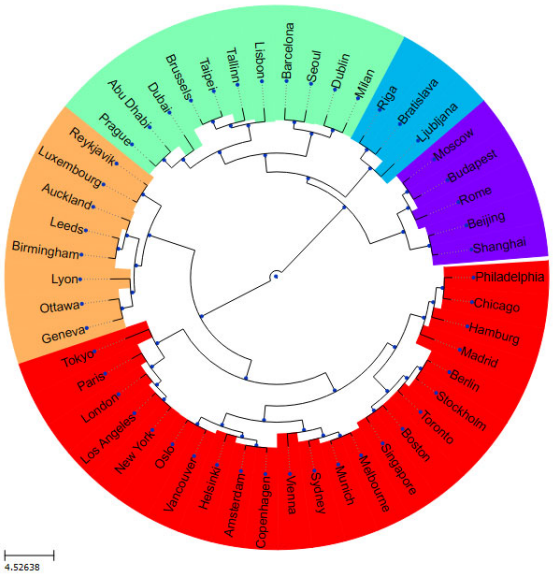

Figure no. 2. Radial dendogram

Source: own processing of authors using Visual Studio Code (Python)

• *Blue cluster:* includes Bratislava in Slovakia, Ljubljana in Slovenia, and Riga in Latvia. The European cities in this cluster present a balanced approach between two analysed dimensions: the adoption of technologies in the smart city and their positive effects on the quality of life. Ljubljana is distinguished by being ranked first, within this cluster, with the largest scores for the Smart City Index, Happy City Index, and Quality of Life Index, reflecting the fact that the advanced adoption of smart city technologies and investments in urban innovations contribute positively to the well-being of its inhabitants. European blue cluster cities seem to reflect a balance between the adoption of smart city technologies and their positive effects on quality of life, and Ljubljana could serve as a model for other cities through good urban innovation practices and their impact on citizens (Naterer, Žižek and Lavrič, 2018). However, the values of the indicators are below the average level for the four indicators, except for the city of Ljubljana, which registers an above average value for the Quality of Life Index.

• *Purple cluster:* includes Beijing, Budapest, Moscow, Rome and Shanghai, cities with a rich historical and cultural past, combining their unique heritage with ambitions for modernization and innovation. The lowest Quality of Life Index scores (at the cluster level) for China's two megalopolises, Beijing and Shanghai, may suggest quality of life challenges, while the Innovation City Index scores for both cities show a strong towards innovation. As with Budapest, Moscow has competitive Smart City Index and Happy City Index scores, which can be seen as an effort to integrate technology into city management and improve the experience of its residents, highlighting at the same time, the fact that innovation remains a priority area for development. As for Rome, the city can be considered the leader of this cluster, in the application of smart urban technologies and in achieving a high level of citizen satisfaction, based on the highest scores for the Smart City Index and the Happy City Index. It should be noted that in addition to the challenges of managing its historical and cultural resources in the context of modernization, Rome maintains its profile as an innovative and lively city (Nicolas, Kim and Chi, 2020). The cluster is characterized by values below the average of the indicators included in the analysis, similar to the cities included in the blue cluster.

• *Red cluster:* includes cities spread across the globe and recognized for their dynamism, high quality of life, and innovative environment. Copenhagen and Oslo are well known for their strong commitment to sustainability and good practice in the smart city concept, while Amsterdam, the city with the highest values

for the Smart City Index and a Happy City Index, both at the cluster level and globally, can be considered a benchmark in the use of technology to improve urban services, which contributes to a high level of happiness and well-being (Kutty et al., 2022). Smart cities such as Helsinki, Sydney and Vancouver, as Nicolas, Kim and Chi (2020) also state, can be considered centers of economic well-being and, at the same time, stand out for the quality of life they offer. Cities such as Tokyo, London, Paris, and New York are global financial centers that, in addition to high values for the Smart City Index, demonstrate a high capacity to integrate and promote innovation, something underlined by the scores for the Innovation City Index (Toh, 2022). On the other hand, cities such as Berlin, Madrid, and Philadelphia show that, despite the challenges, they continue to invest in technology and innovation to improve the quality of urban life, but may still have areas where they can progress (Lai and Cole, 2023). The majority of cities included in this cluster have the highest values for the Smart City Index, Happy City Index, Quality of Life Index, and Innovation City Index, or above average.

- *Orange cluster:* includes cities located both in Europe and North America as well as in Oceania, which may suggest a possible regional trend toward innovative smart city policies and a high quality of life. Simultaneously, smart and sustainable cities represent a global priority, regardless of the geographical region. Geneva and Luxembourg are notable not only for their exceptional quality of life but also for their smart city initiatives. Moreover, Geneva also stands out as the city with the highest score in this cluster for the Happy City Index (Dashkevych and Portnov, 2023).

The data and cluster analysis results suggest that cities can be grouped into distinct clusters on the basis of their performance in sustainability and digital technologies. Each cluster identified in the dendrogram brings together cities with similar performance profiles in the analysed indices, which indicates a similar approach or results in the implementation of sustainability and smart technology solutions. This fact confirms the first research hypothesis (#1) *that cities can be grouped into distinct clusters based on their performance in the dimensions of sustainability and implementation of digital technologies.*

At the same time, there are significant variations in the performance of cities in terms of sustainability and smart technology by geographic region. The dendrogram might reflect this variation, with cities in certain regions tending to cluster together. This may be due to cultural, economic, political, and historical factors that influence how actively a city invests in innovation and sustainability, which confirms the second research hypothesis (#2) *The performance of cities in terms of sustainability and smart technology varies significantly depending on the geographical region.*

Conclusions

In a world of continuous urbanization and digitization, composite indicators measuring the performance of cities in aspects such as technological innovation, citizen happiness, quality of life, and urban innovation capacity are becoming essential tools for urban planning and policy development. The present study focuses on the interpretation of four such composite indicators: the Smart City Index, Happy City Index, Quality of Life Index, and Innovation City Index, each reflecting a vital dimension of urban progress and well-being. By comparing the performance of cities in these areas, the leaders in urban innovation can be identified, and the cities in which these aspects can be improved can be highlighted.

In this context, different models of success and challenges in the evolution of urban sustainability can be observed:

- Auckland and Geneva perfectly exemplify the balance between technological advances and a high quality of life, indicating a strong commitment to sustainability and urban responsibility (Mega, 2022).

- The major urban agglomerations, Tokyo, London and New York, illustrate how metropolises combine new technological breakthroughs and urban infrastructure with the goals of sustainability and improving the quality of life (Shmelev and Shmeleva, 2018), while other large cities, such as Paris, highlight the areas that can be optimized, resulting in improved quality of life.

- Abu Dhabi and Seoul focus on developing advanced technological infrastructure and stimulating innovation, but require improvements in quality of life and dimensions quantified by the happiness index, suggesting the utility of a holistic approach to urban balance (Noori, Hoppe and de Jong, 2020; Al-Azzawi, 2021).

- Similarly, Beijing and Shanghai demonstrate a strong commitment to urban innovation, but lower values for the Quality of Life Index highlight the need to balance rapid growth and innovation with improved living standards to ensure urban sustainability (He et al., 2018).

The results of this study are influenced not only by the availability of data but also by the complexity of each composite indicator included in the analysis. Thus, one of the limitations of this study is its dependence on publicly available indices (Smart City Index, Happy City Index, Quality of Life Index and Innovation City Index) for the classification of cities. At the same time, these indices are sensitive to point analysis, and there is a risk that they do not always reflect the local nuances specific to each city or exclude emerging factors relevant to urban sustainability and smart technologies (direct civic participation in smart city initiatives etc.). To overcome this limitation, a future research direction could include collecting more detailed data, including at the local level, which will provide a clearer insight into the effects of smart and sustainable city initiatives. Depending on the availability of data, added value can be provided by integrating a longitudinal perspective, thus tracking the evolution of smart cities and their sustainability over time to identify trends and assess the impact of long-term interventions. Such research could provide richer and more useful insights for urban innovation policymaking, helping to create smarter and more sustainable cities for the future.

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