International Journal of Business and Management; Vol. 19, No. 5; 2024
ISSN 1833-3850 E-ISSN 1833-8119
Published by Canadian Center of Science and Education

From Smart and Sustainable Cities to Urban Planning: A Conceptual Cluster Analysis

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Received: June 11, 2024 Accepted: July 19, 2024 Online Published: August 12, 2024

doi:10.5539/ijbm.v19n5p152 URL: https://doi.org/10.5539/ijbm.v19n5p152

Abstract

The rapid urbanization anticipated by the United Nations, projecting that 68% of the global population will reside in urban areas by 2050, underlines the escalating challenges such as public health, traffic congestion, and social inequality in cities. Smart cities, utilizing Information and Communication Technologies (ICTs), emerge as a pivotal solution by optimizing urban infrastructure and enhancing life quality, aiming for sustainable urban development that balances economic growth, environmental protection, and social equity. This article systematically explores the intricate relationships among smart city concepts through a cluster analysis, highlighting how these interact within the scope of urban planning to address such multifaceted challenges. The analysis utilizes a bibliometric review and thematic clustering to synthesize existing definitions and characteristics of smart cities, assess the integration of sustainable practices, and identify the intersections where urban planning can effectively leverage ICTs to enhance city livability and sustainability. Our findings suggest that while smart cities are advancing, significant gaps remain, particularly in integrating technology with aging urban infrastructures and ensuring inclusivity in technology access. Future directions are proposed, emphasizing interdisciplinary approaches and the need for adaptive policies that can accommodate rapid technological advancements without compromising the social and environmental fabric of urban life. This study not only advances academic knowledge but also offers practical insights for public and private sectors committed to fostering more intelligent, sustainable cities aligned with global sustainability goals.

Keywords: smart cities, urban planning, sustainable development, urban infrastructure, thematic clustering

1. Introduction

The rapid pace of global urbanization is evidenced by United Nations projections indicating that by 2050, approximately 68% of the world's population will reside in urban areas, compared to 55% in 2018 (United Nations, 2018). This rapid urbanization presents critical challenges for modern cities, including health issues (WHO, 2019), traffic congestion, and increasing social inequality, with clear disparities in access to basic services and economic opportunities (Mahendra et al., 2021). The growth of cities brings about complex urban problems, making the search for innovative solutions essential. In this context, the concept of smart cities, which uses Information and Communication Technologies (ICT) to optimize urban infrastructure and improve quality of life, is gaining prominence (Harrison et al., 2010). The urban sustainability, aiming to balance economic development, environmental protection, and social equity, is an alternative to ensure the future viability of cities (Caragliu, Del Bo, and Nijkamp, 2011).

Previous studies have addressed various dimensions of smart and sustainable cities. For example, Dembski et al. (2020) explored artificial intelligence to support participatory urban planning processes, showing how simulation can improve decision-making (Dembski et al., 2020). Lombardi et al. (2012) proposed a performance evaluation model for smart cities, emphasizing the importance of governance and citizen participation (Lombardi et al., 2012). Additionally, studies such as those by Albino, Berardi, and Dangelico (2015) explored the intersection between ICTs and sustainability, highlighting the need for an integrated approach (Albino, Berardi, and Dangelico, 2015).

Analyzing the complexity and diversity of these factors, urban planning is essential for integrating advanced technologies into the urban environment, improving citizens' quality of life. Smart urban planning uses data and information technology to optimize urban services such as transportation, energy, and waste management, making cities more efficient, sustainable, and resilient (Townsend, 2013). It should promote active citizen participation in urban development, ensuring that solutions align with the real needs of the population. Therefore, effective urban planning is a fundamental element for creating sustainable, efficient, and people-centered smart cities (Komninos, 2015).

Even though ICT mechanisms are crucial for urban infrastructure, optimizing services, and improving citizens' quality of life, it is necessary to also consider the sustainability of cities. Harrison et al. (2010) highlight the relevance of these technologies, indicating that their integration is an essential basis for creating smart cities. Albino, Berardi, and Dangelico (2015) reinforce this view, arguing that combining ICTs with sustainable practices can significantly improve resource efficiency and urban quality of life.

Sustainability is a central pillar in smart cities and should be integrated into all urban dimensions. Caragliu, Del Bo, and Nijkamp (2011) argue that sustainability, along with economic development and social equity, should be a strategy to ensure sustainable and fair urban development. Batta et al. (2015) also discuss the importance of integrating sustainability, technology, and urban planning. Urban planning must also incorporate active citizen participation, which is essential for urban performance. Lombardi et al. (2012) emphasize the importance of governance and citizen participation, suggesting that inclusive governance is vital for building smart cities. Deakin and Allwinkle (2007) complement this view by discussing the importance of inclusive governance in smart cities.

However, there is still a significant gap in the literature regarding the complex interrelationship of the multiple components that constitute a truly smart and sustainable city. This study aims to fill this gap by providing a systematic analysis of how these concepts are developed and interrelated in the production of knowledge focused on urban planning.

The article seeks to relate the study of sustainable cities with sustainable urban planning through a systematic analysis of concepts. To achieve this, it aims to a) compile and analyze the definitions, characteristics, and main concepts of smart cities in the academic literature, providing a solid theoretical foundation for the study; b) identify the various approaches of the articles, separating them into analytical clusters of studies with the analysis of concepts and technologies that have proven effective in promoting sustainable urban development; c) identify the intersection between urban planning and sustainability to understand how urban planning can be used as a tool to achieve urban sustainability.

The methodology of this article is based on a systematic literature review to identify and analyze the main academic contributions on sustainable cities and sustainable urban planning. For data analysis, a Big Data analysis was conducted through a Text-Based Thematic Clustering process, developed to categorize and analyze large sets of textual data, such as scientific articles. The article used natural language processing (NLP) techniques and clustering algorithms to identify predominant themes and group documents according to their thematic similarity.

Thus, this study seeks not only to advance academic knowledge but also to provide practical tools that can be used by professionals in the public and private sectors to promote smarter and more sustainable cities, aligned with global sustainable development goals.

2. Literature Review

The concept of smart cities has become one of the central pillars in the contemporary debate on sustainable urban development. Involving the integration of digital technologies, these cities aim to optimize urban management, promote environmental sustainability, and improve citizens' quality of life. However, the discussion of knowledge surrounding smart cities is frequently accompanied by criticisms and questions about their real effectiveness in addressing urban challenges.

Evans et al. (2019) present a critical view of the notion of smart cities. Although these cities promise to generate economic, social, and environmental value through the integrated connection of urban services and digital infrastructures, there is a scarcity of evidence regarding their capacity to improve social well-being, build just and equitable communities, reduce resource consumption and waste generation, improve environmental quality, or decrease carbon emissions.

One of the main challenges of smart cities is their tendency to reinforce neoliberal logic and consumerist culture, primarily benefiting more affluent populations. Evans et al. (2019) highlight that smart urban development tends to focus on populations that can access private services, such as Uber and Airbnb, marginalizing those who do not have access to these resources. Additionally, Viitanen and Kingston (2014) discuss how urban sustainability is often reconfigured as a market opportunity for corporations to sell digital solutions, which can lead to the marginalization of citizens and the prioritization of superficial solutions over deeper structural changes.

Lovell (2019) explores the specific challenges of smart grid projects, arguing that digital technologies often do not behave as planned, creating governance failures and limiting expected social benefits. Despite these challenges, there is a growing recognition of the potential of smart technologies to promote more sustainable and inclusive urban development.

For smart cities to truly contribute to sustainable development, Evans et al. (2019) suggest that smart applications must be aligned with neighborhood and city scales, rather than focusing solely on individual consumer behavior and international commercial agendas. They argue that smart city policy should build collective agendas and visions around relevant social and environmental issues at the local level.

Trencher (2018) proposes a more humanized view of smart cities, where technology is used to address significant social problems, emphasizing the importance of involving citizens in the smart urban development process and ensuring that technologies are used to improve quality of life.

Various studies have explored different aspects of smart cities, including governance, technological infrastructure, sustainability, and citizen participation. Cocchia (2014) conducts a systematic literature review on smart cities, identifying key themes and research trends. The integration of these areas is fundamental for the success of urban planning in smart cities (Allwinkle & Cruickshank, 2011).

Giffinger et al. (2007) define smart cities based on six main characteristics: smart economy, smart mobility, smart environment, smart people, smart living, and smart governance. Caragliu, Del Bo, and Nijkamp (2011) define smart cities as those where investments in human and social capital, along with traditional (transportation) and modern (ICT) infrastructure, promote sustainable economic growth and high quality of life, with smart resource management through participatory governance. Chourabi et al. (2012) propose an integrative framework to understand smart cities, emphasizing the integration of technology, people, and institutions. Hollands (2008) criticizes the term 'smart cities' as often being used superficially, arguing that a smart city should be socially inclusive and sustainable.

For this work, we use the concept that smart cities are urban environments that utilize ICTs to optimize public services, promote sustainability, and improve quality of life. The integration of technological infrastructure, sustainable practices, and participatory governance should be considered, ensuring inclusion and efficiency with rational management of natural resources and citizen participation for balanced and resilient urban development.

Themes such as smart city governance are discussed in the literature. Chourabi et al. (2012) highlight that effective smart city governance involves the integration of ICT in administrative processes, promoting transparency and citizen participation in decision-making. This approach is essential to ensure that smart technologies are used equitably and inclusively, with urban planning promoting governance structures that facilitate this integration (Gil-Garcia, Zhang & Puron-Cid, 2016).

Bibri and Krogstie (2017) argue that the adoption of technologies such as IoT, big data, and AI is essential for real-time data collection and analysis, allowing for more efficient and responsive urban management. This technological infrastructure is the foundation upon which smart solutions to urban challenges are built, which must be coordinated by managers competent in implementing these technologies to ensure their effectiveness (Neirotti et al., 2014).

According to Yigitcanlar et al. (2018), smart cities have the potential to promote more sustainable urban practices, such as reducing energy consumption, minimizing waste, and improving urban mobility. These benefits are achieved through the integration of technologies that monitor and manage urban resources efficiently, integrated into the city's infrastructure (Caird & Hallett, 2019).

Despite advances, there are still gaps in the literature that need to be addressed. Dameri and Rosenthal-Sabroux (2014) highlight the need for more research focused on bibliometric analysis to map the evolution of the field and identify key actors and trends in smart city research. Additionally, it is important to explore how different cities are implementing smart technologies and what success factors and obstacles they face to develop more informed and effective strategies (Tranos & Gertner, 2012).

Urban planning is a fundamental component in the development of smart cities, as it provides the necessary structure to integrate advanced technologies cohesively and efficiently. According to Batty (2013), urban planning involves organizing and managing urban space to meet the present and future needs of the population. In smart cities, this means creating an environment that allows for the implementation and harmonious operation of information and communication technologies (ICT), ensuring that these innovations truly improve citizens' quality of life by coordinating infrastructure, services, and resources, providing sustainable and inclusive development.

The integration of ICT in urban planning enables the creation of intelligent resource management systems, such as water, energy, and transportation. Bibri and Krogstie (2017) highlight that these technologies allow real-time data collection and analysis, facilitating informed decision-making and the implementation of more efficient solutions. Intelligent transportation systems can reduce congestion and improve urban mobility, while smart energy grids can optimize electricity consumption and reduce waste. However, for these technologies to be effective, urban planning must foresee and accommodate their implementation, ensuring that all parts of the city are connected and function in an integrated manner.

As discussed by Yigitcanlar et al. (2018), sustainable urban practices are essential to reducing environmental impact and improving city resilience. This includes the incorporation of green areas, the promotion of efficient public transport, and the implementation of intelligent waste management systems. These sustainable initiatives should be an integral part of city development, creating an environment that supports and promotes environmentally friendly practices, anticipating future challenges such as climate change, and developing strategies to mitigate their effects.

To ensure inclusion and equity in the development of smart cities, citizen participation is crucial. Urban planning must facilitate this participation, ensuring that all voices are heard and considered. This can be achieved through the creation of digital platforms that allow citizens to contribute ideas and feedback, as well as through public consultations and workshops. Furthermore, urban planning must address existing inequalities and work to ensure that the benefits of smart technologies are distributed fairly, avoiding the creation of a digital divide that could exacerbate social inequalities (Cardullo and Kitchin, 2018).

2. Method

Given the objectives of this article, a systematic conceptual analysis was chosen as it is a research method used to investigate scientific progress. This technique consists of the quantitative analysis of scientific publications to produce qualitative evaluations of the number of publications, knowledge dissemination, techniques and technologies adopted for problem-solving in a specific scientific area, authorship patterns of publications, among other aspects.

2.1 Data Collection

A bibliometric study was used to examine the scientific production on smart cities correlated with urban planning. This allowed for the recognition of the researchers and funding agencies within the international scientific community. It should be emphasized that this study uses a systematic analysis to examine the scientific production on smart cities. Although this methodology is effective in identifying trends and patterns in the literature, it aims to delve into the individual studies of each author, given the number of works used. Furthermore, the study is predominantly based on a conceptual analysis and literature review, which will not take into account the incorporation of empirical data or detailed case studies, given the proposed theoretical contribution.

The Web of Science database was chosen as it is considered one of the best databases for conducting systematic bibliometric research due to reasons such as: Comprehensive and Multidisciplinary Coverage, as it offers extensive coverage of various scientific disciplines, including social sciences, natural sciences, engineering, humanities, among others; Quality and Relevance of Publications, considering that journals indexed in Web of Science undergo rigorous evaluation and selection processes, ensuring high quality and relevance of the publications. This ensures that the data used in the bibliometric analysis comes from reliable sources (Web of Science, 2024).

2.2 Text-Based Thematic Clustering

Cluster analysis of scientific articles is a powerful methodology for identifying patterns and relationships among different research areas. In the context of smart cities, this approach can reveal emerging trends, identify knowledge gaps, and promote a more comprehensive understanding of the topics discussed. Using the K-means algorithm, the analysis groups articles based on their keywords and research areas, allowing for a clear visualization of the various subareas that comprise the field of smart cities.

The method of text-based thematic clustering can be considered a form of Big Data analysis, given its ability to handle large volumes of textual data, the diversity of data types, and the use of advanced processing and analysis techniques. By applying this method, researchers and professionals can obtain valuable insights that help guide studies and policies in smart cities and urban planning.

It should be noted that while this methodology is useful for identifying predominant themes, it can simplify the complexity of textual data, failing to capture important nuances of the analyzed studies.

2.2.1 Processing Information through Big Data

To process the data, the “Data Analysis & Report AI” model developed by Kenneth Bastian was used, leveraging the AI processing capabilities of GPT-4 from OpenAI. For cluster analysis, the articles were vectorized using the Term Frequency-Inverse Document Frequency (TF-IDF) technique, which transforms the text into a numerical format that can be processed by the machine learning algorithm.

Initially, a Microsoft Excel file containing the metadata of the articles (title, abstract, keywords, year of publication, and citations) extracted from the Web of Science, as described in the previous step, was used. Text preprocessing involved cleaning and preparing the texts for analysis, including removing stopwords, normalization, and lemmatization. With the cleaned texts, NLP criteria were applied to transform the texts into vectors. Subsequently, TF-IDF embeddings (Term Frequency-Inverse Document Frequency) were created.

The K-means algorithm was then applied to identify nine distinct clusters. Dimensionality reduction was performed for data visualization, facilitating the interpretation of the results. The representative articles of each cluster were reviewed to identify the predominant themes.

3. Results

3.1 Data Collected

The data presented in the table summarize the results of a research conducted in the Web of Science on the topic "Smart City" or "Smart Cities". The research was conducted in three stages, applying different filters to refine the results and obtain a more specific view of the available articles.

Table 1. Stages of analysis and exclusion criteria for bibliometric analysis

DATA BASE	WEB OF SCIENCE		
Filter 01	“Smart City” or “Smart Cities” (all fields)	Filter 02	“Smart City” or “Smart Cities” (all fields) AND “Urban Planning” (all fields)
Result 1	Article (43.654)	Result 2	Article (1.773)
Filter 03	Years: 2015 a 2024	Filter 03	Document type: Article Languages: English
Result 3	Article (1.724)	Result 3	Article (1.180)

Source. Data of the Research.

In the first stage, the search string "Smart City" or "Smart Cities" was used without restrictions on the type of document or language. This initial search returned a total of 43,654 articles, reflecting the popularity and broad scope of the topic "Smart Cities" in academic literature. In the second stage, an additional filter was applied using the search string "Smart City" or "Smart Cities" AND "Urban Planning" in all fields, maintaining the same collection period. This filter reduced the number of articles to 1,773, indicating that a smaller number of studies directly address the intersection between smart cities and urban planning.

Finally, in the third and fourth stages, the results were further refined to include only articles published between 2015 and 2024, written in English, and of the type "Article." With these additional restrictions, the number of articles was reduced to 1,180. This final refinement highlights a collection of recent and high-quality academic works that are relevant to understanding the most current trends and developments in the field of smart cities and urban planning.

3.2 Exploration of Concepts through Clustering

Cluster analysis allows for a quick identification of which research areas are rapidly growing and which themes are emerging in the field of smart cities. Such an understanding is crucial for researchers who need to focus on investigations that would have the most immediate impact and relevance at the pace of current development.

Smart cities are an interdisciplinary field that encompasses technology, architecture and urban planning, sustainability, and governance, to name a few. The process of clustering allows to see how these disciplines are related and work together and, as a result, to facilitate interdisciplinary collaboration. By clustering existing literature into analytical clusters, it is possible to understand where certain areas of knowledge are currently under-researched. Such an insight subsequently helps researchers to pinpoint areas of low representation well and to contribute to a more well-rounded development of knowledge.

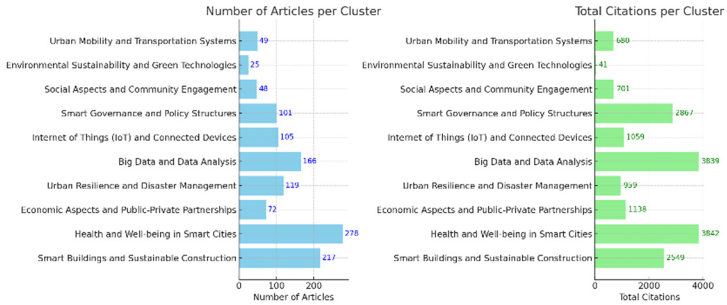

Figure 1. Distribution of Articles by Cluster

3.2.1 Urban Mobility and Transport Systems

The cluster "Urban Mobility and Transport Systems" encompasses 49 articles, totaling 680 citations in the Web of Science Core Collection. This volume of citations indicates significant and ongoing interest in this area, reflecting the relevance and impact of studies conducted on urban mobility and transport systems in the context of smart cities.

This cluster covers research focused on optimizing and innovating urban transport systems through the use of intelligent technologies. Among the main concepts are urban mobility, intelligent transport systems (ITS), the integration of intelligent infrastructure, and data analysis for urban planning.

Urban mobility is fundamental to the planning of smart cities, directly impacting the quality of life, environmental sustainability, and economic efficiency of cities. Newman and Kenworthy (1999) highlight the importance of well-planned transport systems to reduce the carbon footprint and improve public health. Batty et al. (2012) assert that the integration of ICT into transport systems can significantly reduce congestion and pollution.

Intelligent Transport Systems (ITS) utilize information and communication technologies (ICT) to enhance traffic management and transport services, as exemplified by intelligent traffic lights and real-time traffic monitoring systems. The integration of intelligent infrastructure addresses the interconnection of different transport modes and the adaptation of urban infrastructure to support these integrations sustainably.

Data analysis employs big data and advanced analytics to understand mobility patterns and user behavior, enabling more effective and predictive urban planning. These concepts correlate by contributing to more efficient, sustainable, and citizen-centered transport systems.

Studies show that the application of ITS can transform the management of transport resources, providing a more efficient approach. For example, public transport systems that use real-time data can adjust their routes and schedules based on demand, improving user experience and resource utilization. Litman (2013) argues that transport efficiency is vital for urban sustainability, while Rodrigue, Comtois, and Slack (2016) emphasize the need for advanced technologies to address mobility challenges in cities.

Improvements in urban mobility have positive spillover effects in various areas. Economically, cities with efficient transport systems tend to attract more investment and talent, boosting economic growth (Glaeser, 2011). Socially, accessible transport systems promote social inclusion, ensuring that all citizens have access to economic and social opportunities (Banister, 2008). The efficient mobility facilitates more integrated urban planning, where transport, housing, and land use are cohesively considered (Cervero, 2013).

3.2.2 Environmental Sustainability and Green Technologies

The cluster "Environmental Sustainability and Green Technologies" encompasses 25 articles, totaling 41 citations in the Web of Science Core Collection. Despite the smaller number of articles and citations compared to other clusters, this group addresses a critical theme for the sustainable development of smart cities.

This cluster focuses on research on environmental sustainability and the development of green technologies. The main concepts include environmental sustainability, renewable energy solutions, and the impact of urbanization on natural resources.

Environmental sustainability refers to practices and policies aimed at conserving natural resources and minimizing negative environmental impacts. Renewable energy solutions, such as solar and wind energy, are frequently explored to reduce dependence on fossil fuels and mitigate climate change. The impact of urbanization on natural resources is a central theme, investigating how urban growth affects land use, water, and other resources.

These concepts are interrelated in that they all seek to promote urban development that is environmentally sustainable and contributes to the resilience of cities in the face of climate change.

Environmental sustainability is a fundamental pillar in the planning of smart cities. Authors like Newman (2006) highlight the importance of integrating sustainable practices into urban planning to ensure that city growth does not compromise the environment. McKinsey & Company (2011) suggests that green technologies are essential for improving energy efficiency and reducing carbon emissions.

Additionally, research shows that the implementation of renewable energy solutions can lead to significant reductions in energy costs and the carbon footprint of cities (Jacobson & Delucchi, 2011). Studies by Rosenzweig et al. (2010) emphasize the importance of developing resilient urban infrastructures that can withstand the impacts of climate change.

The relevance of this cluster is reinforced by the growing global awareness of the need for sustainable urban practices and the role of cities in the fight against climate change. Green technologies and renewable energies are seen as key instruments to achieve these goals.

Environmental sustainability is closely linked to other critical aspects of urban planning. Economically, sustainable practices can reduce long-term costs and attract investments in clean technologies (Kahn, 2006). Socially, sustainable cities tend to offer a better quality of life, with access to green spaces, cleaner air, and a healthier environment (Beatley, 2011).

The environmental sustainability promotes social justice by ensuring that the benefits of a healthy environment are accessible to all citizens, regardless of their socioeconomic status, to create more equitable and inclusive cities (Agyeman, Bullard, & Evans, 2003).

3.2.3 Social Aspects and Community Engagement

The cluster "Social Aspects and Community Engagement" encompasses 48 articles, totaling 701 citations in the Web of Science Core Collection. This volume of citations indicates significant interest and relevance of research on social aspects and community engagement in the context of smart cities.

This cluster focuses on the importance of social aspects and community engagement in the construction of smart cities. The main concepts involve analyzing how smart technologies impact citizens' lives, addressing issues of inclusion, equity, and access to services. This includes Community Engagement, strategies, and practices aimed at involving citizens in decision-making and urban planning. Community engagement is essential to ensure that implemented solutions meet the real needs of the population. Additionally, Inclusive Urban Planning entails the creation of policies and urban practices that consider the diversity of the population, ensuring that all social groups have equal access to the benefits of smart cities. These concepts correlate by promoting active citizen participation in urban development, which is fundamental to creating more just, inclusive, and sustainable cities.

Community engagement and social aspects are crucial for the success of smart cities. Caragliu, Del Bo, and Nijkamp (2011) highlight that smart cities are not only about technology but also about the ability to attract and retain creative human capital. Authors like Hollands (2008) argue that the true intelligence of a city lies in its ability to respond to the needs of its citizens.

Moreover, social inclusion in urban planning is essential to ensure that all communities have access to the benefits of smart technologies. Putnam (2000) suggests that social capital, which includes networks of relationships and trust among citizens, is fundamental to social cohesion and sustainable urban development. Research shows that cities investing in community engagement and social inclusion tend to be more resilient and adaptable (Evans et al., 2016). This is because citizens who feel heard and included are more likely to support urban initiatives and collaborate to solve local challenges.

The relevance of community engagement and social aspects extends to various other areas. For example, active citizen engagement can improve the efficiency of public policies and increase transparency and trust in government (Fung, 2006).

Socially, inclusive practices promote equity and reduce urban inequalities, ensuring that all citizens have access to opportunities and services (Sen, 1999). This is vital for creating cohesive and harmonious urban communities. Economically, social inclusion can boost innovation and creativity, as the diversity of perspectives contributes to more effective and innovative solutions (Florida, 2002).

3.2.4 Smart Governance and Policy Frameworks

The cluster "Smart Governance and Policy Frameworks" encompasses 101 articles, totaling 2867 citations in the Web of Science Core Collection. This significant volume of articles and citations underscores the importance of research focused on smart governance and urban policies in the context of smart cities.

This cluster addresses how smart cities are managed and the policies that support this management. The main concepts include smart governance, policy frameworks, and data-driven decision-making. Smart governance refers to the use of digital technologies to improve efficiency and transparency in public administration. This includes integrated management systems and citizen participation platforms. Policy frameworks involve creating regulations that promote sustainable development and social inclusion. Data-driven decision-making uses big data to inform governance decisions, enabling quick and accurate responses to citizens' needs. These concepts are interdependent, as smart governance requires well-defined policies and data-driven decisions to be effective.

Smart governance is crucial for the success of smart cities. Meijer and Bolívar (2016) highlight that effective governance coordinates technologies and initiatives, while Hollands (2015) argues that the true intelligence of a city lies in its governance and adaptability. The transparency and citizen participation promoted by smart governance increase public trust in local governments (Nam & Pardo, 2011).

Data-driven decision-making enhances the efficiency of public services such as healthcare, transportation, and security (Chourabi et al., 2012). This is made possible by the analysis of large volumes of data in real-time, allowing for more agile and precise responses. Angelidou (2017) asserts that data-driven governance is essential for sustainable urban development.

Smart governance and policy frameworks influence various critical areas of urban development. Socially, inclusive and transparent policies promote social justice and equity, ensuring universal access to the benefits of smart cities (Sen, 1999). Economically, efficient governance attracts investment and stimulates economic growth (Glaeser, 2011).

Moreover, smart governance facilitates coordination between different sectors and levels of government, promoting an integrated approach to urban development (Batty et al., 2012). This is vital for addressing complex challenges such as climate change and rapid urbanization. Gil-Garcia (2014), Pardo, and Nam (2016) emphasize the importance of collaborative governance for the effective implementation of smart cities.

3.2.5 Internet of Things (IoT) and Connected Devices

The cluster "Internet of Things (IoT) and Connected Devices" encompasses 105 articles, totaling 1059 citations in the Web of Science Core Collection. These numbers demonstrate a growing and significant interest in the application of IoT for the development of smart cities.

This cluster focuses on the utilization of the Internet of Things (IoT) and connected devices in urban environments. The main concepts include IoT, smart sensors, data collection, and urban applications. IoT refers to the interconnection of devices through the internet, enabling real-time communication and data exchange. Smart sensors are devices that collect environmental and operational data, essential for the implementation of IoT solutions. Data collection is fundamental for monitoring and analyzing the functioning of cities, while urban IoT applications range from traffic management to environmental monitoring. These concepts are interconnected, as the effectiveness of IoT solutions depends on the quality of the data collected and the integration of the devices.

IoT is used for the development of smart cities because it allows for more efficient and responsive urban management. Gubbi et al. (2013) highlight that IoT can transform urban management by providing real-time data, improving decision-making. Zanella et al. (2014) argue that IoT facilitates the implementation of smart services, such as adaptive street lighting and waste management.

Recent research shows that IoT can significantly increase energy efficiency and reduce operational costs (Al-Fuqaha et al., 2015). Moreover, the integration of IoT with other technologies, such as big data and artificial intelligence, further enhances its applications, as observed by Lin et al. (2017).

The relevance of IoT in urban planning is reinforced by its ability to create more resilient and adaptable infrastructures. For instance, IoT can improve emergency and disaster management by providing accurate and real-time data to first responders (Aazam et al., 2014).

IoT and connected devices have broad implications for various aspects of urban development. Economically, the implementation of IoT solutions can attract investment and foster technological innovation, creating new business opportunities and jobs (Santucci, 2010). Socially, IoT can improve the quality of life for citizens by offering more efficient and personalized services (Whitmore, Agarwal, & Da Xu, 2015). Additionally, IoT promotes environmental sustainability by optimizing resource use and reducing waste. For example, smart irrigation systems can save water by adapting to real-time weather conditions (Parwez, Rathi, & Sethi, 2017).

3.2.6 Big Data and Data Analytics

The cluster "Big Data and Data Analytics" encompasses 166 articles, totaling 3839 citations in the Web of Science Core Collection. This volume of articles and citations demonstrates the significant interest and importance of research focused on big data and data analytics in the context of smart cities.

This cluster focuses on the utilization of big data and advanced data analytics techniques to improve urban planning and management. The main concepts include big data, predictive analytics, data-driven decision-making, and the integration of artificial intelligence (AI).

Big data refers to large volumes of data that are generated, collected, and analyzed to gain useful insights. Predictive analytics uses this data to forecast future trends and behaviors, aiding in urban planning. Data-driven decision-making allows urban managers to make informed and precise choices, enhancing the efficiency and effectiveness of public services. The integration of AI with big data amplifies these analyses, enabling the automation and optimization of urban processes. These concepts are interconnected, as the effectiveness of using big data depends on the proper analysis and interpretation of the data.

Big data is a crucial tool for the development of smart cities, as it provides the foundation for more efficient and informed urban management. Batty (2013) emphasizes that analyzing large volumes of data can transform how cities are planned and managed. Kitchin (2014) argues that big data allows for a better understanding of urban patterns, facilitating more precise and effective interventions.

Recent research indicates that the use of big data can significantly improve the efficiency of urban services, such as transportation, security, and public health (Hashem et al., 2015). Predictive analytics enables the anticipation of problems and optimization of resources, while AI can automate complex tasks and enhance the accuracy of predictions (Chen, Chiang, & Storey, 2012).

The relevance of big data in urban planning is reinforced by its ability to provide a holistic and integrated view of cities. For instance, big data can be used to monitor and manage traffic in real-time, reducing congestion and improving urban mobility (Wang et al., 2015).

Big data and data analytics have broad implications for various aspects of urban development. Economically, the use of big data can reduce operational costs and increase the efficiency of public services, generating resource savings (Manyika et al., 2011). Socially, data analytics can improve citizens' quality of life by offering more personalized and responsive services (Townsend, 2013). And the big data promotes environmental sustainability by optimizing resource use and reducing waste. For example, data analytics can be used to improve the energy efficiency of buildings and infrastructure systems (Zhou et al., 2016).

3.2.7 Urban Resilience and Disaster Management

The cluster "Urban Resilience and Disaster Management" encompasses 119 articles, totaling 959 citations in the Web of Science Core Collection. This volume of articles and citations indicates the relevance of research focused on urban resilience and disaster management within the context of smart cities.

This cluster addresses the ability of cities to face and recover from natural disasters and other crises. The main concepts include urban resilience, disaster management, risk assessment, and climate change planning.

Urban resilience refers to the capacity of cities to withstand, absorb, and recover from adverse events. Disaster management involves the preparation, response, and recovery from incidents such as earthquakes, floods, and storms. Risk assessment is crucial for identifying vulnerabilities and planning mitigating actions. Climate change planning addresses the adaptation of cities to cope with impacts such as rising sea levels and extreme weather events. These concepts are interconnected, as an effective approach to urban resilience depends on robust disaster management and proactive planning.

Urban resilience is essential for the development of smart cities as it ensures the sustainability and safety of urban communities. Meerow, Newell, and Stults (2016) highlight the importance of integrating resilience into urban planning to tackle the challenges of climate change. Ahern (2011) argues that urban resilience enhances cities' capacity to adapt and recover from disasters.

Recent research indicates that implementing resilience strategies can significantly reduce the economic and social impacts of disasters (Cutter et al., 2013). Risk assessment allows cities to identify vulnerable areas and plan specific interventions, while climate change planning ensures long-term adaptation (Pelling, 2011).

The relevance of urban resilience in smart city planning is reinforced by the need to protect critical infrastructures and ensure the continuity of essential services during crises (Holling, 2016). Moreover, effective disaster management can save lives and reduce economic losses (UNISDR, 2015).

Urban resilience and disaster management have broad implications for various aspects of urban development. Socially, a robust resilience approach promotes the safety and well-being of citizens, ensuring a rapid and effective response to crises (Tierney, 2014). Economically, resilience can reduce costs associated with disasters, protect investments, and attract new businesses (Godschalk, 2003).

Additionally, urban resilience contributes to environmental sustainability by promoting land use and construction practices that minimize negative impacts (Jabareen, 2013). For example, green infrastructures can help control floods and improve air quality while providing recreational spaces for the community.

In summary, the cluster "Urban Resilience and Disaster Management" is essential for the development of smart cities. The integration of resilience strategies allows for more efficient, adaptable, and sustainable urban management, with recognized economic, social, and environmental benefits.

3.2.8 Economic Aspects and Public-Private Partnerships

The cluster "Economic Aspects and Public-Private Partnerships" encompasses 72 articles, totaling 1138 citations in the Web of Science Core Collection. This volume of articles and citations indicates the relevance of research focused on economic aspects and public-private partnerships in the context of smart cities.

This cluster highlights the economic aspects and partnerships between the public and private sectors for the development of smart cities. The Economic Aspects of Smart Cities refer to analyzing the economic impacts of smart city initiatives, including economic growth, job creation, and investment attraction. Public-Private Partnerships (PPPs) involve collaboration between government entities and private companies to finance, build, and operate urban infrastructure projects. Innovative Business Models explore new economic approaches and business models that can be applied to make cities smarter and more efficient.

These concepts are correlated as they promote sustainable and efficient urban development through collaboration between public and private sectors. PPPs are seen as an effective solution for financing and implementing smart city projects, while economic aspects and innovative business models ensure these projects' long-term sustainability.

Economic aspects and public-private partnerships are fundamental for developing smart cities. Zhang et al. (2015) highlight that PPPs can mobilize financial resources and technical expertise to implement complex urban projects. Caragliu, Del Bo, and Nijkamp (2011) argue that economic development is one of the pillars of smart cities, driven by strategic investments and innovation.

Recent research indicates that PPPs can improve the efficiency and effectiveness of urban infrastructure projects, providing benefits for both the public and private sectors (Rouhani & Niemeier, 2014). Moreover, public-private collaboration can accelerate the implementation of smart technologies and promote innovation (Hodge & Greve, 2017).

The relevance of economic aspects in urban planning is reinforced by the need to ensure that smart city projects are financially viable and sustainable. Authors like Dijk, de Jong, and Edelenbos (2015) suggest that innovative business models are essential to attract investments and ensure the long-term sustainability of urban projects.

Public-private partnerships and economic aspects have broad implications for various aspects of urban development. Economically, PPPs can attract significant investments, create jobs, and stimulate local economic growth (Lombardi et al., 2012). Socially, these partnerships can improve the quality of urban services, making cities more livable and inclusive (Van Ham & Koppenjan, 2016).

The PPPs promote innovation and efficiency by allowing the private sector to bring its expertise and resources to public projects (Yuan, Skibniewski, & Li, 2010). This is especially relevant in areas such as transportation, energy, and telecommunications, where smart technologies can be quickly implemented and operated effectively.

In summary, the cluster "Economic Aspects and Public-Private Partnerships" is vital for the development of smart cities. Collaboration between public and private sectors ensures that urban infrastructure projects are financially viable, innovative, and sustainable, with economic, social, and technological benefits widely recognized by recent studies.

3.2.9 Health and Well-Being in Smart Cities

The cluster "Health and Well-Being in Smart Cities" encompasses 278 articles, totaling 3842 citations in the Web of Science Core Collection. This significant volume of articles and citations indicates the relevance of research focused on health and well-being within the context of smart cities.

This cluster studies the applications of smart technologies to improve the health and well-being of urban citizens in three macro concepts. Regarding health in smart cities, it shows the use of advanced technologies to enhance healthcare services, including telemedicine, remote patient monitoring, and connected health systems. Concerning citizens' well-being, it involves using smart technologies to promote a healthy lifestyle, including fitness apps, environmental monitoring, and smart public spaces. Personalized health services consider using big data and artificial intelligence to provide personalized healthcare based on patients' individual needs and conditions.

These concepts are interrelated, as they all seek to improve urban citizens' quality of life through smart technologies. Integrating connected health solutions and personalized services promotes a healthier and more sustainable urban environment.

Health and well-being are crucial components for the success of smart cities. Authors like Allwinkle and Cruickshank (2011) argue that health is one of the fundamental pillars of smart cities, as it directly influences citizens' quality of life and productivity. Marsal-Llacuna, Colomer-Llinàs, and Meléndez-Frigola (2015) highlight that implementing smart technologies in healthcare can reduce costs and improve the efficiency of health services.

Recent research indicates that using technologies like telemedicine and remote monitoring can significantly improve healthcare access and quality (De Albuquerque et al., 2016). Big data analysis allows identifying public health patterns and planning more effective interventions (Islam et al., 2015).

The relevance of health and well-being in urban planning is reinforced by the need to create urban environments that promote health and quality of life. Hollands (2015) argues that smart cities should focus on creating spaces that encourage an active and healthy lifestyle.

Health and well-being have broad implications for various aspects of urban development. Socially, focusing on health can reduce inequalities, ensuring that all citizens have access to quality healthcare (Boulos et al., 2011). Economically, health improvements can increase productivity and reduce long-term healthcare costs (Batty et al., 2012).

Moreover, smart health technologies promote environmental sustainability by optimizing resource use and reducing waste. For example, environmental monitoring systems can help control air and water pollution, improving public health (Dlodlo, Gcaba, & Smith, 2016).

In summary, the cluster "Health and Well-Being in Smart Cities" is essential for developing smart cities. Integrating advanced health technologies and personalized services ensures that citizens live in healthy and sustainable environments, with economic, social, and environmental benefits widely recognized by recent studies.

3.2.10 Smart Buildings and Sustainable Construction

The cluster "Smart Buildings and Sustainable Construction" encompasses 217 articles, totaling 2549 citations in the Web of Science Core Collection. This significant volume of articles and citations highlights the relevance of research focused on smart buildings and sustainable construction in the context of smart cities.

This cluster focuses on using smart technologies and sustainable practices in constructing and operating urban buildings. Smart Buildings involve using advanced technologies such as IoT, automation, and sensors to monitor and control various systems within buildings, such as lighting, HVAC, and security. Sustainable Construction analyzes building practices that minimize environmental impact, including using eco-efficient materials, energy efficiency, and sustainable resource management. The focus on Energy Efficiency studies the application of technologies and practices that reduce energy consumption and increase the operational efficiency of buildings.

These concepts are interrelated, as they all aim to create built environments that are not only technologically advanced but also sustainable and efficient. Integrating smart technologies in buildings promotes more effective resource management and improves the occupants' quality of life.

Smart buildings and sustainable construction are essential for developing smart cities. Authors like Asadi et al. (2012) highlight that energy efficiency in buildings is one of the greatest challenges and opportunities for urban sustainability. On the other hand, Alwan, Jones, and Holgate (2017) argue that sustainable construction is crucial to reduce cities' environmental impact.

Recent research indicates that applying smart technologies in buildings can lead to significant energy savings and operational costs (Marino et al., 2016). Moreover, sustainable construction can improve the health and well-being of occupants by creating healthier and more comfortable indoor environments (Azhar, 2011).

The relevance of smart buildings in urban planning is reinforced by the need to create infrastructures that are resilient and adaptable to climate change. Smart buildings can adapt to environmental conditions in real time, optimizing resource use and improving efficiency (O'Brien, Gaetani, & Gilani, 2017).

Smart buildings and sustainable construction have broad implications for various aspects of urban development. Economically, energy efficiency and reduced operational costs can attract investment and increase property values (Kok, Miller, & Morris, 2011). Socially, sustainable construction practices promote inclusion by providing quality and affordable housing (Dempsey et al., 2011).

Moreover, sustainable construction contributes to environmental preservation by reducing carbon emissions and natural resource consumption (Häkkinen & Belloni, 2011). For example, using recycled materials and implementing water management systems can minimize buildings' environmental impact (Li, Zhao, & Tian, 2011).

In summary, the cluster "Smart Buildings and Sustainable Construction" is vital for developing smart cities. Integrating smart technologies in buildings and sustainable construction practices ensures that urban infrastructure is resilient, efficient, and environmentally friendly, with economic, social, and environmental benefits widely recognized by recent studies.

3.3 Conceptual Clusters Synthesis

The development of smart cities is a multidisciplinary field encompassing a wide range of research and application areas. The table presented below synthesizes the main research clusters identified in the scientific literature, highlighting the number of articles, the total citations in the Web of Science Core Collection (WoS Core), the main concepts addressed by each cluster, and the specific relevance of each to the advancement of smart cities. This analysis provides a comprehensive and detailed overview of contemporary research efforts, highlighting crucial areas for the development and implementation of smart and sustainable solutions in urban areas.

The clusters were categorized based on bibliometric data analysis, identifying areas with the highest scientific production and academic impact. Each cluster represents a distinct yet interconnected facet of smart cities, addressing topics from urban mobility to citizen health and well-being. The table is structured to offer a clear and concise view of the researched topics, allowing readers to quickly understand the trends and main research focuses.

Table 2. Conceptual Clusters Synthesis

Cluster Name	Key Concepts	Relevance to Smart Cities
Urban Mobility and Transportation Systems	Urban mobility, ITS, intelligent infrastructure integration, data analysis	Essential for reducing congestion and improving quality of life by promoting public transportation use
Environmental Sustainability and Green Technologies	Environmental sustainability, renewable energy solutions, impact of urbanization on natural resources	Crucial for sustainable development, reducing the environmental impact of cities
Social Aspects and Community Engagement	Social aspects of smart cities, community engagement, inclusive urban planning	Promotes social inclusion and active citizen participation in urban development
Smart Governance and Policy Structures	Smart governance, policy structures, data-driven decision-making	Crucial for coordinating urban technologies and initiatives, promoting transparency and citizen participation
Internet of Things (IoT) and Connected Devices	IoT, smart sensors, data collection, urban applications	Enables more efficient and responsive urban management, improving citizens' quality of life

Big Data and Data Analysis	Big data, predictive analysis, data-driven decision-making, artificial intelligence	Provides a foundation for more efficient and informed urban management, improving decision-making processes
Urban Resilience and Disaster Management	Urban resilience, disaster management, risk assessment, climate change	Ensures the sustainability and safety of urban communities, reducing disaster impacts
Economic Aspects and Public-Private Partnerships	Economic aspects, public-private partnerships, innovative business models	Attracts investments, creates jobs, and stimulates economic growth through public-private collaboration
Health and Well-Being in Smart Cities	Health, well-being, personalized health services, advanced technologies	Improves quality of life and reduces healthcare costs, promoting healthy lifestyles
Smart Buildings and Sustainable Construction	Smart buildings, sustainable construction, energy efficiency	Promotes sustainability and energy efficiency, improving quality of life and reducing operational costs

3.4 Conceptual Relationships Between Clusters

By analyzing the web correlation graph between smart city clusters, valuable insights can be derived about the interactions and interdependencies among the various thematic areas that constitute the concept of a smart city. This analysis helps to identify how different aspects of smart city development are interconnected and influence each other. Below, a more detailed analytical examination of this graph is presented, highlighting the key relationships and dependencies between clusters, their potential impacts on urban planning and governance, and the implications for future research and practical implementations.

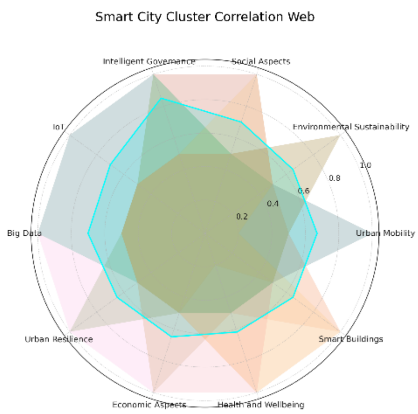

Figure 2. Dependency relationship of concepts by cluster

Clusters with the largest fill areas and the most direct connections to other clusters, such as "Intelligent Governance" and "Big Data," indicate greater centrality in the context of smart cities. This centrality suggests that initiatives in these areas have a broad impact and are critical to the success of other clusters. For example, intelligent governance is fundamental for coordinating the implementation of technologies and policies in other domains.

The analysis of fill areas among clusters shows how seemingly distinct areas are interconnected. "Urban Mobility" and "IoT" exhibit a strong correlation, which is expected since the Internet of Things (IoT) provides the necessary technological infrastructure for innovations in urban mobility, such as intelligent transport systems.

Clusters that show high correlation, such as "Health and Wellbeing" and "Smart Buildings," indicate areas where collaboration can be particularly fruitful. Smart buildings can significantly contribute to health and wellbeing by monitoring and controlling environmental conditions that directly affect residents. Conversely, low correlations, such as between "Urban Mobility" and "Health and Wellbeing," suggest areas that are less directly connected but may still influence each other indirectly.

From a planning perspective, a holistic and integrated approach should be utilized. Projects focused on "Environmental Sustainability" should consider their interactions with "Urban Resilience," especially in the contexts of climate change and disaster management.

Gaps in current research and practices can also be identified. If a cluster has few strong connections, it may indicate an underdeveloped area that could benefit from more investment and innovation. For example, if "Economic Aspects" shows fewer interconnections, it may suggest the need to explore more deeply how technological innovations impact the economic models of cities.

Smart city clusters are interdependent, forming a complex web of interactions that facilitate or hinder various urban initiatives. For instance, advances in "IoT and Connected Devices" have direct implications for "Urban Mobility," where sensors and real-time data can transform traffic management and public transport efficiency (Batty, 2013). Similarly, "Intelligent Governance" relies on "Big Data" to analyze large volumes of urban information, which can be used to improve public services and political decision-making (Kitchin & McArdle, 2016).

4. Discussion

The conception of smart cities involves the holistic integration of technology, infrastructure, and governance to optimize urban efficiency and improve quality of life. This paper delves into the complexities of these integrations, highlighting the relationships between various thematic clusters, exploring existing gaps, and suggesting future directions for the evolution of smart cities.

The emergence of new concepts such as "Participatory Urbanism" and "Adaptive Infrastructures" reflects an evolution in urban thinking. These concepts suggest that cities should be viewed not only as places of habitation but as living ecosystems where citizens have open access to data and can actively contribute to urban planning and governance. This approach promotes greater transparency and citizen participation, which are fundamental for urban sustainability and resilience.

The development of smart cities represents one of the most promising and challenging frontiers of modern urbanization. For these cities to not only thrive technologically but also be sustainable and inclusive, it is crucial to continue exploring new concepts, fostering interdisciplinary collaborations, and, above all, ensuring that urban development is conducted with a strong ethical and human-centered consideration. Future cities must be built with and for their citizens, ensuring that technology serves to enhance, rather than limit, human potential.

Despite the great potential, smart cities face significant challenges. One major challenge is the integration of technological systems with old urban infrastructures, many of which were not designed to support new technologies (Hollands, 2015). The issue of digital inclusion is also critical, as the lack of access to advanced technology can increase social and economic inequality in cities (Vanolo, 2014). Another challenge is to create policies that are adaptable and flexible enough to keep pace with the rapid innovation of technology.

Planning a smart city involves not only the adoption of technologies but also the revision of urban strategies to incorporate these new tools sustainably. This includes ensuring that smart city projects are ecologically sound and economically viable in the long term. Additionally, there is a need to create governance mechanisms that enable effective collaboration between public, private, and community sectors (Nam & Pardo, 2011).

One of the main limitations of this work is the absence of a unified concept of smart cities. Various studies use different criteria and approaches to define what constitutes a smart city, which can lead to varied and inconsistent interpretations. This lack of uniformity makes it difficult to compare results across different studies and to replicate initiatives implemented in diverse urban contexts.

Additionally, there is an excessive tendency in the literature to predominantly focus on technological solutions for urban challenges, neglecting social, political, and cultural aspects that are equally important for the success of smart cities. This fragmented approach can result in an incomplete view of the smart city concept, limiting the understanding of the complex dynamics involved in sustainable urban development.

To advance the development of smart cities, it is essential to explore concepts such as "Urban Flexibility," which refers to a city's ability to adapt and change quickly in response to new information or emergencies. The "Digital Citizen Engagement" can be enhanced through apps and platforms that facilitate residents' direct participation in urban decisions, increasing transparency and trust in institutions (Castelnovo, 2016).

Looking ahead, it is important to explore how emerging technologies can be employed ethically and sustainably. For example, the implementation of "Adaptive Artificial Intelligence" that can learn and evolve within the specific urban context, offering personalized solutions that respect the cultural and social peculiarities of each city. Additionally, incorporating "Biophilic Design" practices in urban spaces can help improve citizens' mental and physical well-being by integrating natural elements more prominently into the urban landscape.

The need for an interdisciplinary approach is more critical than ever. Smart cities encompass a range of disciplines, including data engineering, social sciences, urban planning, urban psychology, and public policy management. Collaboration among these disciplines can lead to more robust and inclusive innovations. For instance, the integration between data engineers and urban planners can create more efficient transportation systems that also promote social interaction and accessibility.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Canadian Center of Science and Education.

The journal and publisher adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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