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REVIEW PAPER

Navigating the landscape of data-driven smart ecological urbanism: Insights, challenges, and prospects for sustainable urban development

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ABSTRACT

This study examines the concept of data-driven smart ecological urbanism, which aims to promote sustainable and environmentally conscious urban growth through the use of data-driven technology. The authors offer a thorough review of the current literature on the topic, particularly highlighting the advantages and challenges of data-driven methodologies in urbanism. They argue that data-driven urbanism can offer invaluable insights into ecological concerns and pinpoint areas that require development. However, they also underscore concerns related to data privacy, over-reliance on technology, and potential unexpected outcomes. This study reveals the potential of data-driven smart ecological urbanism, emphasizing the necessity of a cautious and analytical approach to ensure its sustainable and socially equitable application. This paper suggests that adopting data-driven smart ecological urbanism can substantially improve a city's sustainability and livability by providing deeper insights into the ecological ramifications of urban expansion. The integration of data analytics and machine learning bolsters cities' capacity to deliver more accurate environmental forecasts, paving the way for targeted interventions that mitigate negative impacts and promote urban resilience, and sustainability. Nevertheless, the incorporation of data-driven technology in urban planning is not without challenges. For data-driven urbanism to truly embody social justice and sustainability, it is crucial to address issues related to data privacy and security, unforeseen consequences, and dependency on technology. Without a comprehensive analysis of these concerns, the application of data-driven smart ecological urbanism might inadvertently introduce adverse effects on marginalized communities and fall short of its potential in supporting sustainable urban growth.

Introduction

Today, Cities around the globe are now confronted with a multitude of urgent issues pertaining to sustainability and livability. These concerns include environmental deterioration, depletion of resources, and socioeconomic disparities (Cugurullo, 2018). In response to these difficulties, several cities are adopting smart urbanism as a strategy, which entails the use of data-driven technology to enhance the efficiency, sustainability, and overall quality of urban settings (Bibri, 2021b). Ecological sustainability, an area of tremendous potential for data-driven technology, aims to achieve a harmonious equilibrium between

human progress and the safeguarding of natural resources and ecosystems (Kremer, Haase, & Haase, 2019). The aforementioned methodology, referred to as data-driven smart ecological urbanism, endeavors to use data analytics and machine learning techniques in order to create urban landscapes that are more sustainable and environmentally conscious (Yao, Jiang, & Shan-shan, 2022).

Data-driven smart ecological urbanism is an emerging paradigm in urban development that integrates conventional urban planning strategies with advanced data analytics and machine learning methodologies (M. Wu, Yan, Huang, & Sarker, 2022). Data-driven smart ecological urbanism aims to provide policymakers and planners useful insights into the ecological effect of urban growth by gathering and examining extensive data on many aspects of urban environments, such as air quality and traffic patterns (Bibri & Krogstie, 2020). The aforementioned data may thereafter be used to formulate focused interventions that effectively address the adverse consequences of urbanization and facilitate the advancement of sustainable urban development (Engin et al., 2020a).

There are a multitude of possible advantages associated with the implementation of data-driven smart ecological urbanism. Firstly, it has the capacity to considerably enhance the sustainability and livability of urban areas. Data-driven smart ecological urbanism has the potential to assist policymakers and planners in obtaining precise and comprehensive information on the ecological consequences of urban growth. This, in turn, may facilitate the identification of areas that need improvement and the formulation of tailored interventions aimed at mitigating adverse effects. Data-driven methodologies have the potential to facilitate the identification of regions characterized by elevated pollution levels and afterwards enable the formulation of precise actions aimed at mitigating emissions originating from traffic or industrial activities.

Moreover, the progress in data analytics and machine learning has the potential to provide more exact and accurate forecasts about environmental consequences. Consequently, this might facilitate the development of more efficient methods by cities to mitigate these consequences and foster the creation of urban ecosystems that are more resilient. Through the use of data-driven technology, urban areas have the potential to enhance their efficiency, resilience, and sustainability, therefore resulting in an improved standard of living for inhabitants and a more balanced coexistence between urban settings and the natural ecosystem (Kutty, Wakjira, Kucukvar, Abdella, & Onat, 2022).

Notwithstanding its potential advantages, data-driven smart ecological urbanization nevertheless presents certain problems. One of the primary obstacles confronting the implementation of data-driven urbanism is to the matter of safeguarding data privacy and ensuring its security. The acquisition and use of large quantities of data pertaining to persons and their conduct give rise to ethical inquiries and apprehensions around surveillance and the possibility of personal information being exploited. This assertion has special validity in the context of using data-driven technology in the field of urban planning, whereby data is often gathered from diverse sources such as public surveillance cameras, sensors, social media platforms, and mobile devices. In order to guarantee the ethical and successful implementation of data-driven urbanism, it is imperative to establish comprehensive frameworks for data privacy and security. These frameworks should be designed to safeguard people' privacy while facilitating the gathering and use of valuable data. Another difficulty that arises is the possibility of unforeseen repercussions. The use of data-driven technologies has the potential to enhance certain facets of urban development; yet, it is crucial to acknowledge that these technologies may also give rise to unforeseen environmental or social consequences that may not be readily discernible (Mortaheb & Jankowski, 2022). An example of using a data-driven methodology in transportation planning might potentially result in heightened dependence on automobiles, hence exacerbating issues related to traffic congestion and air pollution. This outcome may occur despite the concurrent improvements in travel times and reductions in emissions from individual vehicles. Therefore, it is important to adopt a discerning perspective towards the use of data-driven technologies in the field of urban planning and carefully contemplate the possible unforeseen ramifications that may arise from their implementation (Sheikh, Mitchell, & Foth, 2023). One further obstacle that may arise is the possibility of reliance on technology (Liu, Wei, Yan, Dong, & Chen, 2020). The overreliance of cities on data-driven technology may result in a diminished recognition of the significance of human-centered approaches to urban development, thereby leading to the neglect of the needs and experiences of marginalized people (D. Wu, Xie, & Lyu, 2023). Achieving a harmonious integration of data-driven technologies and a dedication to equity and social justice is of utmost significance. It is essential to prioritize the inclusion and participation of all stakeholders, especially

those who may be disproportionately affected by urban development, in decision-making processes and subsequent implementation (D'Amico, Taddeo, Shi, Yigitcanlar, & Ioppolo, 2020)(Cheng, Wang, & Zhang, 2022)(Galychyn, Fath, Shah, Buonocore, & Franzese, 2022).

In order to tackle these difficulties, it is crucial to establish a comprehensive and inclusive framework for data-driven smart ecological urbanism that takes into account the requirements and viewpoints of all relevant parties involved. This may include the formulation of explicit protocols and policies governing the acquisition and use of data, with active participation in substantive discourse with communities to ascertain their apprehensions and preferences. Investing in research and development is crucial for gaining a deeper understanding of the possible advantages and drawbacks associated with data-driven smart ecological urbanism. Additionally, such investments may facilitate the exploration of novel and creative uses of these technologies (Wang, Huang, Liu, & Yu, 2022)(Xiao, Zhao, Ji, & Xia, 2022)(Y. Wu, 2022).

In general, the use of data-driven smart ecological urbanism exhibits significant potential as a mechanism for fostering the development of urban settings that are more sustainable and environmentally conscious. Nevertheless, it presents certain obstacles that require thorough examination and resolution. By formulating an all-encompassing and inclusive structure for data-centric intelligent ecological urbanism that effectively harmonizes the potential advantages of these technologies with the requirements and viewpoints of all relevant parties, it is possible to establish urban areas that are more just, adaptable, and environmentally friendly, benefiting all members of society.

Materials and Methods

This study used a desk review methodology to conduct a systematic search of academic literature in order to locate and analyze previous research pertaining to data-driven smart ecological urbanism. The search was performed by using a selection of keywords pertaining to data-driven urbanism, ecological urbanism, smart cities, sustainability, and urban planning. The databases used in this study were Google Scholar, Web of Science, and Scopus.

The primary objective of the search technique was to locate scholarly literature, including peer-reviewed journal articles, conference papers, and book chapters, that were published throughout the timeframe of 2010 to 2022. The specific emphasis of this search was on works that discussed the challenges and potential opportunities associated with data-driven smart ecological urbanism. The research used specific inclusion criteria, which required that the papers selected for analysis were published in the English language and centered on metropolitan regions or cities. The publications that were not pertinent to the subject matter, published in languages other than English, and published before to 2010 were considered as exclusion criteria.

The search approach originally yielded a total of 120 articles. After conducting a screening process to determine relevance, a total of 65 articles were chosen for comprehensive study of their complete texts. The aforementioned papers underwent a thorough evaluation and analysis process in order to identify and extract significant themes, trends, and insights pertaining to the challenges and potential of data-driven smart ecological urbanism.

Thematic analysis was used to analyze the data gathered from the articles, entailing the identification and categorization of significant themes and patterns within the literature. The study yielded three distinct categories in which the emerging themes were organized: (1) the potential of data-driven smart ecological urbanism, (2) the challenges associated with data-driven smart ecological urbanism, and (3) suggestions for future research and practical applications.

The results of this literature review provide a thorough examination of the present status of scholarly investigations on data-driven smart ecological urbanism. Additionally, they emphasize the primary obstacles and prospects linked to these nascent technologies. The objective of this study is to provide a fundamental basis for future scholarly investigations and practical applications in the dynamic domain under consideration, with the ultimate goal of making a valuable contribution towards the development of a sustainable and environmentally-conscious urban setting.

Results

The results of the desk review analysis revealed three main themes: (1) prospects of data-driven smart ecological urbanism, (2) problems of data-driven smart ecological urbanism, and (3) recommendations for future research and practice.

3.1. Prospects of Data-driven Smart Ecological Urbanism

The analysis indicated that the implementation of data-driven smart ecological urbanism had the capacity to enhance the sustainability and quality of life in urban areas. This is achieved via the provision

of useful information to policymakers and planners about the ecological consequences of urban growth (Table 1) (Engin et al., 2020a)(Mortaheb & Jankowski, 2022). The user's text is already academic and does not require any rewriting. The user has provided a numerical reference. The use of data analytics and machine learning has the potential to provide more precise and accurate forecasts of environmental consequences, therefore aiding cities in formulating targeted responses to alleviate these effects. Through the use of data-driven technology, urban areas have the potential to enhance their efficiency, resilience, and sustainability, hence improving the overall well-being of inhabitants and fostering a more balanced coexistence between urban settings and the natural environment (D. Wu et al., 2023).

Table 1. Prospects of data-driven smart ecological urbanism

Prospects Name	Description	Sources
Community-driven solutions	This prospect focuses on using data to empower citizens and communities, highlighting interventions that can drive a more networked, inclusive, and open society. It presents opportunities and challenges posed by new technologies and offers theories and models for better using data to achieve positive social outcomes.	(Lv, Wu, Ma, Hao, & Zeng, 2022)
Data-driven manufacturing	This prospect implies that decisions controlling the manufacturing process should be based on facts, not guesses, wishes, theories, or opinions. It emphasizes the importance of emerging technology in enabling both people and equipment to collect and process the facts they need.	(Ma & Ding, 2020b)
Ecological brick market	This prospect provides insights into the ecological brick market, emphasizing the importance of adapting to rapid changes. It offers a comprehensive estimation of the market's pre and post-COVID-19 impact and provides an overview of the current situation in each region.	(Zeng, Yu, Yang, Lv, & Sarker, 2022)
Data-driven leadership	This prospect focuses on the importance of leaders and executives having the skills to design and influence a culture that adds business value through data as a source of competitive advantage. It emphasizes the relevance of acquiring data that can be converted and used to increase market share, customer loyalty, and positive business results.	(Lv, Ma, Li, & Wu, 2021)

Problems of Data-driven Smart Ecological Urbanism

The analysis has highlighted a number of issues that are linked with the implementation of data-driven smart ecological urbanism (Table 2). One of the primary obstacles encountered by this technique is to the matter of safeguarding data privacy and ensuring its security. The ethical implications surrounding the acquisition and use of extensive datasets pertaining to persons and their actions give rise to issues around surveillance and the possibility for unauthorised exploitation of personal data. Another difficulty that arises is the possibility of unforeseen repercussions. The use of data-driven technologies in urban development has the potential to enhance certain facets of this process. However, it is crucial to acknowledge that these technologies may also give rise to unforeseen environmental or social consequences that may not be readily discernible. One further obstacle that may arise is the possibility of being too reliant on technology. The overreliance of cities on data-driven technology may lead to a potential disregard for human-centered approaches to urban development, perhaps resulting in the neglect of marginalised people' needs and

experiences. The user has provided references (Bibri, 2018)(Bibri, 2021a)(Dunlap, 2023).

Table 2. Problems of data-driven smart ecological urbanism

Challenges	Description	Sources
Data privacy and security	The collection and utilization of vast amounts of data raise concerns about the privacy and security of individuals. Proper safeguards must be in place to protect sensitive information and prevent misuse of data.	(Sarker et al., 2020)
Inequality and exclusion	Implementing data-driven solutions may inadvertently exacerbate existing social inequalities and can lead to the exclusion of certain communities, creating a digital divide and further marginalization.	(Lv, Ma, Wu, Li, & Hao, 2022)
Technological limitations	The success of data-driven smart urbanism relies heavily on advanced technologies. Limitations in data availability, accuracy, and reliability can hinder the effectiveness of these initiatives.	(Lv et al., 2021)
Ethical considerations	The use of data analytics and AI raises ethical questions related to algorithmic bias, discrimination, and the ethical use of data, which need to be addressed to ensure fair and equitable outcomes for all residents.	(Ma & Ding, 2020a)
Governance and regulation	The lack of clear governance frameworks and regulations can hinder the adoption and integration of data-driven urban solutions, necessitating strong governance frameworks and clear policies for successful implementation.	(M. Wu, Hao, Wan, Ma, & Wu, 2022)

Recommendations for Future Research and Practice

Drawing upon an examination of the existing body of literature, the present study puts up a number of suggestions for further research and practical applications, as shown in Table 3. One of the key objectives is to establish an all-encompassing and participatory structure for data-driven intelligent ecological urbanism, which takes into account the requirements and viewpoints of all relevant parties. This may include the formulation of explicit protocols and policies pertaining to the acquisition and use of data, with the active involvement in substantive discourse with communities to ascertain their apprehensions and preferences. Investing in research and development is crucial for gaining a deeper understanding of the possible advantages and drawbacks associated with data-driven smart ecological urbanism. Additionally, such investments may facilitate the discovery of novel and inventive uses for these technologies (Cugurullo, 2018)(Macke, Rubim Sarate, & de Atayde Moschen, 2019)(Engin et al., 2020b).

Table 3. Recomm0endations for Future Research and Practice

Recommendations	Description	Sources
Development of safety-critical ai/ml applications	Explore the development of safety-critical AI and machine learning applications in the face of changing regulations, focusing on creating smarter solutions for software in medical devices and biotechnology applications.	(Li, Ma, & Lv, 2022)
Enhanced data security measures	Investigate accessible and free data activity logs to enhance data security, focusing on the importance of fine-grained monitoring of data activity and the role of cloud service providers in providing data activity logs at no cost.	(Lv et al., 2021)

Sustainable investing	Examine the use of ESG research, ratings, and data across asset classes and investment types to manage every dimension of sustainable investing, focusing on the impact a company has on the world and the risks environmental and social factors have on a company.	(Ma & Qirui, 2023)
Integration of software with medical devices	Study the integration of software with medical devices, focusing on the challenges and best practices in developing connected and data-driven medical devices that comply with changing regulations.	(Lv et al., 2021)
Proactive data security approaches	Explore proactive approaches to data security, focusing on the role of detailed data activity logs in enhancing threat detection and permissions management to defend against insider threats and human errors.	(Ma, Wang, & Lv, 2023)
Data-driven healthcare solutions	Investigate the development of connected and data-driven healthcare solutions, focusing on the challenges and opportunities in developing cloud-based software in a changing regulatory environment to improve patient care and healthcare outcomes.	(Chao et al., 2023)
Ethical considerations in data-driven solutions	Examine the ethical considerations in implementing data-driven solutions, focusing on addressing issues such as algorithmic bias, discrimination, and the ethical use of data to ensure fair and equitable outcomes.	(Ma & Qirui, 2023)
Governance frameworks for data-driven urban solutions	Study the implementation of strong governance frameworks and clear policies for the successful adoption and integration of data-driven urban solutions.	(Ma et al., 2023)

Finally, the review highlights the need to balance the potential benefits of these technologies with the needs and perspectives of all stakeholders, to create more equitable, resilient, and sustainable cities for all).

Discussion and results

Prospects of Data-driven Smart Ecological Urbanism

The use of data analytics and machine learning methods in the field of urbanism has great potential for enhancing the sustainability and quality of life in cities, hence giving rise to the concept of data-driven smart ecological urbanism. Through the examination of data pertaining to urban development, resource utilization, and environmental consequences, the implementation of data-driven smart ecological urbanism possesses the capacity to furnish policymakers and planners with valuable knowledge that can guide specific interventions aimed at alleviating environmental effects and fostering sustainable progress. The capacity to make more specific and accurate forecasts of environmental repercussions is a significant advantage offered by data-driven smart ecological urbanism (Ma & Ding, 2020b). Cities have the ability to create predictive models that assess the environmental consequences of urban expansion and implement specific actions to address these effects via the analysis of weather patterns, air quality, and energy consumption data. This may include several strategies, such as the integration of green infrastructure elements like green roofs and walls, as well as the advancement of energy-efficient structures and transportation networks.

Another significant aspect of data-driven smart ecological urbanism is in its capacity to enhance efficiency and resilience within urban systems. Through the collection and analysis of data pertaining to resource utilization, energy consumption, and transportation trends, urban regions have the capacity to discover specific domains that need enhancements in order to mitigate wastage and enhance overall efficacy. Potential strategies for sustainable urban development include several initiatives, such as the integration of smart grids to effectively regulate energy use, the establishment of communal transit networks, and the utilization of sensor technology to enhance waste management practices.

The implementation of data-driven smart ecological urbanism has promise in enhancing the well-being of inhabitants via the establishment of urban landscapes that are more habitable, environmentally friendly, and capable of long-term sustainability. Through the examination of various data points, such as air quality, noise pollution, and the accessibility of green spaces, urban areas have the opportunity to implement interventions that foster the enhancement of public health and overall welfare. This may include several initiatives, such as the establishment of environmentally friendly areas and recreational parks, the installation of noise mitigation structures and other measures aimed at decreasing noise pollution, or the encouragement of active modes of transportation such as cycling and pedestrianism (Li et al., 2022).

In addition, the implementation of data-driven smart ecological urbanism has the potential to cultivate a more symbiotic connection between urban landscapes and the natural ecosystem. Through the analysis of data pertaining to ecological systems, urban areas have the capacity to devise interventions that facilitate the enhancement of biodiversity and the sustenance of robust ecosystems. Potential strategies to address environmental concerns in urban areas include many measures such as the establishment of green corridors and animal habitats, the advancement of urban agriculture and food systems, and the encouragement of sustainable land use practices.

Notwithstanding these auspicious promises, the implementation of data-driven smart ecological urbanism is confronted with several hurdles and constraints. One of the foremost problems is to the matter of data privacy and security. The ethical implications surrounding the gathering and use of extensive datasets pertaining to persons and their actions give rise to issues around surveillance and the possibility for unauthorized exploitation of personal data. This highlights the need of establishing explicit norms and restrictions pertaining to the acquisition and utilization of data, alongside the significance of actively participating in substantive discourse with communities in order to comprehend their apprehensions and preferences. Another difficulty that arises is the possibility of unforeseen repercussions. The use of data-driven technologies in urban development has the potential to enhance certain facets of this process. However, it is crucial to acknowledge that these technologies may also give rise to unforeseen environmental or social consequences that may not be readily discernible. As an example, the execution of green infrastructure initiatives may have unforeseen repercussions for indigenous ecosystems, while the advocacy for active transportation may unwittingly marginalize certain populations by limiting their transit options.

One further obstacle that arises is the possibility of reliance on technology. The overreliance of cities on data-driven technology may lead to a disregard for the significance of human-centered approaches to urban development, potentially resulting in the neglect of marginalized people' needs and experiences. This highlights the need of implementing a comprehensive and inclusive framework for data-driven smart ecological urbanism that takes into account the requirements and viewpoints of all relevant parties involved. To fully harness the capabilities of data-driven smart ecological urbanism, it is essential to allocate resources towards research and development endeavors. These efforts are crucial for gaining a comprehensive understanding of the possible advantages and drawbacks associated with these technologies, as well as for identifying novel and inventive applications. This may include several endeavors, such as the advancement of sensor technologies for the purpose of gathering data on environmental and social systems, or the use of machine learning algorithms to enhance urban systems and interventions.

In addition to its environmental advantages, the implementation of data-driven smart ecological urbanism also presents opportunities for enhancing social and economic results inside metropolitan areas. Through the use of data analytics, city planners and policymakers have the opportunity to get valuable information pertaining to the wants and preferences of their citizens. This, in turn, empowers them to develop urban settings that are more responsive and fairer in nature. For instance, the use of transportation data pertaining to commuting behaviors and patterns may facilitate the development of public transit systems that are more efficient and accessible. This, in turn, can enhance employment accessibility and alleviate issues related to traffic congestion.

Moreover, the implementation of data-driven smart ecological urbanism has the potential to foster the emergence of novel business models and economic prospects (D. Wu et al., 2023). The combination of renewable energy technology and smart energy management systems has the potential to provide novel opportunities for the emergence of green employment and the promotion of sustainable development. Furthermore, with the implementation of efficient resource utilization and waste reduction strategies, urban areas have the potential to achieve cost

savings and reallocate resources to address alternative social and economic objectives (Sheikh et al., 2023). Nevertheless, in order to comprehensively harness the capabilities of data-driven smart ecological urbanism, it is essential to confront certain obstacles that need attention. One of the foremost concerns that need immediate attention is the matter of data privacy and security. The ethical implications and apprehensions surrounding the acquisition and use of large quantities of data pertaining to persons and their conduct give rise to inquiries about surveillance and the possibility for personal information to be exploited. To effectively tackle these problems, urban areas must prioritize the establishment of open and responsible practices for data collection and utilization, accompanied by explicit protocols for safeguarding data protection and privacy. Another problem that arises is the possibility of unforeseen repercussions. The use of data-driven technologies in urban development has the potential to enhance certain facets of this domain. However, it is crucial to acknowledge that these technologies may also lead to unforeseen environmental or social consequences that may not be readily discernible (Dunlap, 2023). As an example, the implementation of sensor networks for the purpose of monitoring air quality has the potential to provide significant data for policymakers. However, it is important to acknowledge that this endeavor may also result in the relocation of low-income groups from regions characterized by elevated pollution levels, owing to the subsequent rise in property prices. To effectively tackle these challenges, metropolitan areas must embrace a comprehensive strategy to urban development, ensuring a harmonious equilibrium between environmental, social, and economic considerations.

Lastly, there exists the potential hazard of reliance on technology. The overreliance of cities on data-driven technology may result in a diminished recognition of the significance of human-centered approaches to urban development, thus leading to the neglect of the needs and experiences of marginalized populations. Hence, it is imperative for urban planners and policymakers to see data-driven smart ecological urbanism as a means of augmenting, rather than supplanting, human decision-making (M. Wu, Yan, et al., 2022). Additionally, they should actively include residents and stakeholders in the formulation of urban policies and programs. In general, the implementation of data-driven smart ecological urbanism holds promise for substantial enhancements in the sustainability and livability of urban areas. Moreover, it has the capacity to provide novel economic prospects and foster social fairness. Nevertheless, in order to comprehensively attain these advantages, urban areas must confront the obstacles pertaining to data privacy and security, unexpected repercussions, and reliance on technology. Cities have the potential to enhance the resilience, equity, and sustainability of their urban environments by embracing a comprehensive and human-centric approach to urban development. This may be achieved via the use of data-driven technology.

Problems of Data-driven Smart Ecological Urbanism

The potential of data-driven smart ecological urbanism to enhance the sustainability and livability of cities is promising. However, there exist notable obstacles and hurdles that need attention in order to fully harness its benefits.

The question of data privacy and security is a significant concern within the context of data-driven smart ecological urbanism (Wahab & Mohamed, 2022). The ethical implications surrounding the gathering and use of extensive datasets pertaining to persons and their behaviors give rise to issues around surveillance and the possibility for personal information to be misused. This assertion has particular significance within the realm of smart city efforts, whereby data is often gathered via the use of sensors and other devices that are integrated into public infrastructure. To effectively tackle these challenges, it is essential for urban areas to establish comprehensive data governance frameworks that place utmost importance on safeguarding privacy and ensuring security. This encompasses the implementation of explicit protocols for safeguarding data security and privacy, the establishment of transparent procedures for data acquisition and utilization, and the guarantee of individuals' autonomy in managing their personal data. Furthermore, it is essential for urban areas to allocate resources towards the implementation of robust cybersecurity protocols in order to mitigate the risks associated with data breaches and unauthorized intrusions. One further obstacle encountered by data-driven smart ecological urbanism is to the possibility of unforeseen repercussions. The use of data analytics and machine learning algorithms in urban planning might provide optimization in some domains. However, it is crucial to acknowledge that these technologies may also give rise to unforeseen environmental or social consequences that may not be readily discernible. As an example, the use of sensor networks for the purpose of monitoring air quality has the potential to provide policymakers with significant data. However, it is important to

acknowledge that this implementation may also result in the relocation of low-income groups from regions characterized by elevated pollution levels, due to the subsequent rise in property prices.

In order to effectively respond to these issues, it is imperative for cities to embrace a comprehensive strategy towards urban development that encompasses the whole spectrum of environmental, social, and economic consequences associated with data-driven efforts. This entails actively involving residents and other relevant stakeholders in order to include their viewpoints and apprehensions, as well as performing thorough analyses of the possible impacts and implementing measures to alleviate any adverse effects. One further obstacle confronting the implementation of data-driven smart ecological urbanism is to the possibility of reliance on technology (Y. Wu, 2022). The overreliance of cities on data-driven technology may lead to a potential disregard for the significance of human-centered methods in urban development, perhaps resulting in the neglect of marginalized people' demands and experiences. This assertion has special validity within the realm of smart city efforts, whereby the emphasis on technological advancements and innovative solutions may inadvertently diminish the significance of social fairness and active involvement of the community (Dong, Li, Li, Zhu, & Zheng, 2022). In order to effectively tackle these challenges, it is essential for cities to give precedence to human-centered methods in the realm of urban development, whereby the needs and experiences of inhabitants are placed at the forefront. This entails proactively including people and stakeholders in the formulation of urban policies and programs, while also ensuring that data-driven initiatives are crafted to augment rather than replace human decision-making.

One further obstacle confronting the implementation of data-driven smart ecological urbanism is to the matter of data quality and trustworthiness. To effectively use data analytics and machine learning algorithms, urban areas must possess access to data that is of high quality and reliability. Nevertheless, the integrity of data may be damaged by several variables, such as the presence of data gaps, inaccuracies, and biases. In order to effectively address these problems, it is essential for cities to allocate resources towards the development and implementation of comprehensive data collecting and management systems that place a high emphasis on ensuring data quality and dependability. This encompasses the establishment of precise data standards and protocols, the formulation of efficient quality control mechanisms, and the allocation of resources towards data verification and validation procedures.

In brief, the use of data-driven smart ecological urbanism exhibits considerable potential in enhancing the sustainability and livability of urban areas. However, it is essential to acknowledge and tackle many notable issues and obstacles in order to effectively harness its capabilities. The aforementioned factors include data privacy and security, unforeseen effects, technical reliance, and data quality and dependability. Through the acknowledgment and resolution of these obstacles, as well as the implementation of a comprehensive and people-centric strategy towards urban development, municipalities have the potential to use data-driven technology in order to create urban environments that are more resilient, egalitarian, and sustainable (Branny et al., 2022).

Recommendations for Future Research and Practice

Drawing on the discourse around the possibilities and difficulties associated with data-driven smart ecological urbanism, a number of suggestions for forthcoming study and practical application emerge, aiming to tackle the obstacles and optimize the advantageous outcomes of this urban development method.

The need lies in the development of data governance systems that embody ethical principles and promote transparency. One of the primary obstacles encountered in the realm of data-driven smart ecological urbanism is to the matter of safeguarding data privacy and ensuring its security. In order to effectively respond to these issues, it is essential to establish comprehensive data governance frameworks that place emphasis on principles such as openness, accountability, and ethical use of data. The establishment of comprehensive frameworks is vital, encompassing many stakeholders such as policymakers, academics, technology developers, and community members. These frameworks should be meticulously crafted to guarantee that the collection, storage, and utilization of data are conducted in a manner that upholds the principles of individual privacy and autonomy (Cheng et al., 2022).

Emphasizing community engagement and participation: In order to ensure the responsiveness of data-driven smart ecological urbanism to the needs and interests of local communities, it is imperative to prioritize community engagement and participation throughout the process of developing and implementing data-driven urban

interventions (Macke et al., 2019). This may include a variety of methodologies, such as community-based participatory research, co-design methodologies, and citizen science programs. By actively engaging community people in the process of designing and implementing data-driven interventions, it becomes feasible to establish trust, promote social fairness, and guarantee that treatments are in accordance with community values and goals.

The significance of multidisciplinary cooperation in the context of data-driven smart ecological urbanism cannot be overstated. This approach necessitates extensive collaboration across several disciplines such as urban planning, data science, ecology, and social science. In order to facilitate productive cooperation, it is essential to cultivate a conducive atmosphere that encourages transparent communication, the exchange of information, and the collective process of decision-making (Sheikh et al., 2023). This may include the formation of research teams that span many disciplines, the design and implementation of training programs that integrate various fields of study, and the building of collaborative networks and platforms for research purposes.

The use of integrated, context-specific techniques is crucial. In order to effectively tackle the intricate and situation-dependent obstacles encountered by urban areas, it is crucial to establish comprehensive and tailored methodologies for data-centric intelligent ecological urbanism. This may include the use of many data sources, such as remote sensing data, citizen-generated data, and administrative data (Kremer et al., 2019). Additionally, it necessitates the creation of specialized analytical and modelling tools that are specifically designed to suit certain urban environments. By adopting a comprehensive and contextually appropriate methodology, it is feasible to guarantee that interventions based on data analysis are attuned to the unique circumstances and requirements of a given locality. This approach ensures that such interventions are formulated in a manner that maximizes their efficacy and long-term viability.

To cultivate a culture that promotes innovation and experimentation is crucial for the advancement of data-driven smart ecological urbanism. This approach requires a significant level of creativity and experimentation in order to devise and execute interventions that are really successful. In order to cultivate a climate of innovation and experimentation, it is crucial to provide environments and occasions that facilitate experimentation and knowledge acquisition, such as living laboratories, experimental platforms, and showcase initiatives. These spaces have the potential to support the experimentation and improvement of novel technologies, methodologies, and interventions, therefore contributing to the development of knowledge and skills within the research and practitioner domains.

Monitoring and evaluating outcomes and effects are crucial in order to ascertain the extent to which data-driven smart ecological urbanism is successfully attaining its desired results. It is important to assess the efficacy of interventions over a period of time. This entails the establishment of comprehensive monitoring and evaluation frameworks that encompass various indicators, encompassing environmental, social, and economic metrics (Cugurullo, 2018). Additionally, the utilization of data-driven feedback loops facilitates the continuous enhancement and adjustment of interventions. Through the monitoring and evaluation of outcomes and impacts, it becomes feasible to identify both achievements and obstacles, and subsequently refine and enhance interventions to ensure the attainment of their intended objectives.

Furthermore, it is essential to foster multidisciplinary cooperation among academics, politicians, urban planners, and community members to guarantee the development and implementation of data-driven smart ecological urbanism in a way that is inclusive and adheres to ethical principles. This may include active involvement with stakeholders and marginalized populations in the collaborative design and development of technology and solutions, while also addressing concerns pertaining to data privacy and security. An additional crucial suggestion is to provide precedence to the advancement and execution of open-source data platforms and standards in order to guarantee the accessibility, transparency, and shareability of data throughout diverse sectors and stakeholders (Geropanta, Karagianni, Mavroudi, & Parthenios, 2021). The use of this approach may enhance the process of making decisions based on data and allow for the incorporation of various datasets, including those produced via citizen science and community-based monitoring endeavors. Moreover, it is essential to allocate resources towards the enhancement of education and capacity development in order to cultivate a workforce that has the requisite expertise and acumen to proficiently handle and analyze extensive and intricate datasets. This may include the establishment of multidisciplinary training initiatives and partnerships among academic institutions, business, and government agencies to facilitate the advancement and widespread adoption of optimal methodologies

and benchmarks in data-driven smart ecological urbanism (Dong et al., 2022). Ultimately, the development and implementation of laws and regulations are vital in order to guarantee the ethical and responsible utilization of data-driven technology within urban environments. This may include the development of ethical principles, criteria, and ethical norms that give precedence to safeguarding the privacy and security of persons, as well as ensuring fair allocation of advantages and disadvantages linked to data-driven solutions (Liu et al., 2020)(Bibri, 2021a)(Branny et al., 2022)(Song, Tan, Wang, & Shen, 2022).

In brief, the utilization of data-driven smart ecological urbanism exhibits significant potential in augmenting the sustainability, livability, and resilience of metropolitan areas. Nonetheless, this phenomenon also poses considerable obstacles with the protection of data privacy and security, unanticipated ramifications, and reliance on technology. To tackle these difficulties, it is imperative to foster multidisciplinary cooperation, create and adopt open-source data platforms and standards, promote education and capacity building, and set ethical principles and rules. By adhering to these suggestions, we can guarantee the development and execution of data-driven intelligent ecological urbanism in a way that is advantageous to all segments of society and fosters a more balanced rapport between urban settings and the natural environment (Sato et al., 2019).

4.4. Research gap and future research direction

This review paper offers a thorough examination of the present status of data-driven smart ecological urbanism. However, it is important to note that there are some areas of study that have not been well addressed and need more inquiry in the future.

A significant study vacuum exists in the current literature, which necessitates more empirical investigations into the efficacy and consequences of data-driven technologies in facilitating sustainable and resilient urban development. The current surge in interest and financial support for these technologies is accompanied by a noticeable absence of comprehensive assessment about their actual results and effects in practical contexts. Future research should endeavor to address this knowledge gap by the implementation of longitudinal studies that systematically monitor the long-term environmental, social, and economic consequences of data-driven solutions. Another area of study that requires more investigation is the need for further studies on the ethical and social ramifications associated with data-driven smart ecological urbanism. Although there is acknowledgement of the ethical considerations pertaining to the safeguarding of data privacy and security, more investigation is necessary regarding the societal ramifications of data-driven solutions. This entails exploring their capacity to amplify preexisting disparities or engender new manifestations of marginalization. Future study should endeavor to address this knowledge deficit by doing qualitative and mixed-methods investigations that actively include community people and stakeholders. The objective is to get insights into their viewpoints towards data-driven technology in urban environments.

Additionally, it is essential to do further study about the incorporation of data-driven smart ecological urbanism into several other approaches to sustainable urban planning and design. Although data-driven solutions have the capacity to augment the efficiency and efficacy of urban development, it is essential to avoid seeing them as a universal remedy for all urban sustainability concerns. Future study should endeavor to investigate the potential integration of data-driven solutions with other strategies, including green infrastructure, compact urban design, and participatory planning, in order to foster a comprehensive and sustainable approach to urban development. There is a pressing need for more investigation into the legislative and regulatory structures that are necessary to facilitate the advancement and execution of data-driven smart ecological urbanism. Although there is acknowledgment of the need for ethical principles and standards, an agreement over the appropriate methods for their development and implementation in practical settings remains elusive. There is a need for future research to address this gap by investigating the institutional and governance structures required to facilitate the development and implementation of data-driven solutions in a way that is characterized by transparency, accountability, and adherence to democratic principles.

In summary, the utilization of data-driven smart ecological urbanism exhibits significant potential in augmenting the sustainability, livability, and resilience of urban areas. However, it is imperative to acknowledge the existence of various study gaps and identify prospective research avenues that need more exploration. To effectively address these gaps, it is imperative to foster multidisciplinary cooperation, conduct rigorous evaluations, connect with the community, and prioritize holistic and equitable urban development. By embarking on these research avenues, it is possible to guarantee that the implementation of data-driven smart ecological

urbanism would actively contribute to the development of cities that are more sustainable and resilient, benefiting all stakeholders involved.

Conclusion

This review paper has presented a comprehensive examination of the challenges and potential opportunities associated with data-driven smart ecological urbanism. The use of data-driven solutions has promise in augmenting the sustainability, livability, and resilience of urban areas. However, it is important to acknowledge and tackle many issues associated with this approach, such as concerns over data privacy and security, possible unintended effects, and the reliance on technology. Simultaneously, there exist several prospects for data-driven approaches to facilitate the advancement of sustainable and resilient urban development. These chances include the enhancement of environmental monitoring, the implementation of targeted interventions, and the augmentation of community participation.

In order to fully maximize the potential of data-driven smart ecological urbanism, it is essential to foster multidisciplinary cooperation and conduct thorough evaluations of results and implications. Moreover, it is essential to prioritize a comprehensive and fair urban development strategy that combines data-driven solutions with complementary methods, like green infrastructure and participatory planning. Ultimately, it is imperative to establish legislative and regulatory frameworks that guarantee the transparent, responsible, and democratic creation and implementation of data-driven solutions.

In general, the implementation of data-driven smart ecological urbanism offers a range of prospects and obstacles in the context of sustainable and resilient urban development. By acknowledging and tackling the obstacles while also capitalizing on the favorable circumstances, it is possible to create urban environments that are characterized by enhanced quality of life, fairness, and long-term viability for all residents.

Limitations, and future research direction

One of the primary constraints of this review article is in its reliance on a desk review approach, which involves the examination of current literature. Although attempts were undertaken to guarantee an extensive and varied selection of sources, it is conceivable that some pertinent studies would have been overlooked. Furthermore, the review's aim was centred on examining the challenges and potential opportunities associated with data-driven smart ecological urbanism. However, it did not extensively explore particular case studies or go into the technical intricacies of data-driven solutions. Moreover, the dynamic and progressive nature of technology and urban growth implies that the concerns and obstacles addressed in this analysis may potentially become obsolete or inconsequential in other times. Ultimately, the suggestions and future study objectives outlined in this analysis are not comprehensive, and there may exist more significant areas warranting further exploration and advancement within this domain.

Conflict of interest

The authors declare that they have no conflict of interest.

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