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Artificial Intelligence for Adaptive and Sustainable Urban Public Spaces

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Abstract

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The development of information technology and rapid urbanization has encouraged the emergence of the concept of smart cities as a solution to modern urban challenges. One of the important aspects of smart cities is urban public spaces, which function not only as social and cultural means, but also as adaptive infrastructure that can improve the quality of life of its citizens. This article discusses the role of Artificial Intelligence (AI) in the development of smart, efficient, and sustainable urban public spaces. By adopting a precedent study approach through descriptive qualitative research methods, this study examines the implementation of AI in various aspects, such as energy management, adaptive lighting, traffic management, and sensor-based security systems. The results of the study show that AI has the potential to strengthen the efficiency of public space governance, improve citizen experience, and support urban sustainability. However, there are also challenges related to data availability, privacy, and infrastructure needs. This study is expected to make a theoretical and practical contribution to the development of smart public spaces in the future.

1. Introduction

In the ever-growing digital era, information technology has permeated almost all aspects of human life, including urban governance. The phenomenon of rapid urbanization brings major challenges, such as population increase, congestion, pollution, and limited public space, which demand innovative and sustainable solutions. The concept of smart city emerged as an answer to the complexity of modern cities by utilizing technology to improve efficiency, security, and quality of life for city residents. In this context, the development of public space is not only seen as a purely physical element, but also as an adaptive space that is able to respond to social and environmental dynamics through intelligent technology.[1]

One of the key components in the development of smart cities is Artificial Intelligence (AI). This technology plays a role in optimizing various sectors, ranging from transportation, energy, urban governance, to public space. AI enables the integration of data obtained from IoT sensors and devices to support fast and accurate evidence-based decision-making. For example, AI-based predictive systems can help city governments monitor citizens' mobility patterns, regulate energy use, and anticipate potential risks in public spaces.[2] Public space itself has a fundamental role in urban social, economic, and cultural life. Its presence as a place for citizen interaction requires design and management that is adaptive to the needs of the community.

[1] Anabel Ortega-Fernández, Rodrigo Martín-Rojas, and Víctor Jesús García-Morales. "Artificial intelligence in the urban environment: Smart cities as models for developing innovation and sustainability." *Sustainability* 12, no. 19 (2020): 7860.

[2] Zaheer Allam and Zaynah A. Dhunny. "On big data, artificial intelligence and smart cities." *Cities* 89 (2019): 80-91.

By utilizing AI, public spaces can be developed to be more interactive and responsive. For example, adaptive lighting in city parks that is adjusted to the level of crowds, or sensor-based waste management systems that monitor capacity in real-time. This technology allows public spaces to be safer, more efficient, and environmentally friendly.[3] The urgency of studying AI in the development of smart public spaces is increasingly prominent due to the increasing need for urban efficiency and sustainability. AI not only speeds up the decision-making process, but also improves the user experience of public spaces. For example, cities with AI-based systems can direct traffic flows to reduce congestion or optimally regulate public energy use. Thus, AI acts as a catalyst in creating an urban environment that is adaptive, comfortable, and supports the quality of life of its citizens.[4]

Previous research has shown that the application of AI in smart cities has touched various fields, including transportation, energy management, and city governance. However, studies on the specific role of AI in the development of urban public spaces are still relatively limited. In fact, public space is the face of the city that is most often used by residents on a daily basis. Therefore, this research is important to deepen understanding of how AI can be leveraged to create smart, adaptive, and sustainable public spaces. By reviewing precedent studies and related literature, this article aims to make contributions both theoretically and practically,

[3] Alexandros Nikitas, Kalliopi Michalakopoulou, Eric Tchouamou Njoya, and Dimitris Karampatzakis. "Artificial intelligence, transport and the smart city: Definitions and dimensions of a new mobility era." *Sustainability* 12, no. 7 (2020): 2789.

[4] Zaib Ullah, Fadi Al-Turjman, Leonardo Mostarda, and Roberto Gagliardi. "Applications of artificial intelligence and machine learning in smart cities." *Computer communications* 154 (2020): 313-323.

as well as offer insights for academics, governments, and the community in designing smart technology-based urban development policies.[5]

2. Literature Review

Studies on Artificial Intelligence (AI) in smart city development have grown rapidly in recent years, covering various aspects such as transportation, energy, governance, and public spaces. Several studies confirm that AI has great potential in supporting city efficiency through large-scale data analysis, prediction of citizen behavior, and automation of governance processes. For example, Batty[6] elaborates that the integration of AI in smart cities enables the realization of a more sustainable urban ecosystem with the support of real-time data that can be used for strategic decision-making. In addition, Cugurullo[7] emphasized the importance of the concept of Urban Artificial Intelligence, namely how AI is not only seen as a tool for automation, but also as an entity that is able to support the autonomy of cities in regulating themselves.

This gives an idea that the development of AI-based public spaces can be directed to create adaptive interactions between citizens and their environment, for example through automated lighting systems or intelligent security monitoring. In

[5] Praise Suharmanto. "Artificial Intelligence-Driven Innovation in Smart City." *National Scientific Symposium & Call for Paper Unindra (Simponi)* 1, no. 1 (2019): 578-589.
[6] Michael Batty. "Artificial intelligence and smart cities." *Environment and Planning B: Urban Analytics and City Science* 45, no. 1 (2018): 3-6.
[7] Federico Cugurullo. "Urban artificial intelligence: From automation to autonomy in the smart city." *Frontiers in Sustainable Cities* 2 (2020): 38.

the context of public space, Suharmanto[8] shows that AI can be an important catalyst in providing a public space that is responsive to people's needs. Smart public spaces not only play a role as a place of social interaction, but also become a strategic instrument in achieving the city's sustainability goals. Thus, the existing literature shows that research related to AI and smart cities has developed widely, but there is still an opportunity to deepen the study of the specific contribution of AI in the development of urban public spaces.

3. Method

This study uses a descriptive qualitative approach with the aim of understanding in depth the role of Artificial Intelligence (AI) in the development of smart and sustainable urban public spaces. This approach was chosen because qualitative research is able to capture the social, technological, and policy dynamics involved in the application of AI in the context of smart cities. The focus of the research is not only on the exposure of the technology used, but also on how the technology interacts with the needs of citizens and affects the governance of public spaces. The method used is a precedent study, which is an analysis of various researches, reports, and real implementations that are relevant to the topic of AI and the public space. Precedent studies are seen as appropriate because they allow researchers to review a wide range of existing cases, identify best practices, as well

[8] Praise Suharmanto. "Artificial Intelligence-Driven Innovation in Smart City." *National Scientific Symposium & Call for Paper Unindra (Simponi)* 1, no. 1 (2019): 578-589.

as critique the challenges that arise in the application of smart technologies in public spaces.

Thus, this study does not aim to test quantitative hypotheses, but rather to present a comprehensive understanding of the developing phenomenon. The research stage begins with the collection of literature from various academic sources, especially scientific articles published between last five years. These sources were chosen to ensure that the data and findings analysed are still relevant to the latest developments in urban technology and policy. The literature was obtained through the Google Scholar database with keywords such as Artificial Intelligence, Smart City, Urban Public Space, and Adaptive Public Infrastructure. The selected articles were then selected based on thematic relevance, credibility, and contribution to the understanding of smart public spaces.

Furthermore, a thematic analysis was carried out on the selected literature. This analysis includes the grouping of key issues such as the role of AI in energy efficiency, urban mobility management, public safety systems, and the user experience of public spaces. Through thematic analysis, research can identify patterns, similarities, and differences among precedent studies, as well as find research gaps that have not been widely explored. The results of this stage were used to compile a conceptual synthesis of how AI can act as a catalyst in creating smart, adaptive, and sustainable urban public spaces. In addition, this approach also helps to link theory with real practice, resulting in recommendations that are not only academic, but also applicable to policymakers and urban planners.

4. Results

4.1. Energy Efficiency and Management in Public Spaces

The application of Artificial Intelligence (AI) in the energy management of urban public spaces makes a significant contribution to efficiency and sustainability. Modern cities face major challenges in energy consumption, especially for public facilities such as street lighting, city parks, public buildings, and urban transportation. AI is present as a solution with its ability to analyze real-time data, predict energy needs, and automatically regulate distribution to be more economical and environmentally friendly. According to Ortega-Fernández et al.[9] smart cities use AI to integrate data from various sensors so that energy distribution can be regulated according to actual needs. For example, lighting in public spaces can be adjusted based on the level of activity of residents; The intensity of the light is lowered when the public space is quiet and increased when it is crowded. This practice not only reduces energy consumption, but also strengthens the safety and comfort aspects of the community.

Another study by Ullah et al.[10] confirms that the integration of AI with energy infrastructure allows for the creation of more adaptive management systems. AI is able to predict energy consumption based on historical patterns and environmental conditions, so that city managers can make strategic decisions related to energy

[9] Anabel Ortega-Fernández, Rodrigo Martín-Rojas, and Víctor Jesús García-Morales. "Artificial intelligence in the urban environment: Smart cities as models for developing innovation and sustainability." *Sustainability* 12, no. 19 (2020): 7860.

[10] Zaib Ullah, Fadi Al-Turjman, Leonardo Mostarda, and Roberto Gagliardi. "Applications of artificial intelligence and machine learning in smart cities." *Computer communications* 154 (2020): 313-323.

planning. This is especially relevant in public spaces where activities are volatile, such as city parks, squares, or sports facilities. In addition, Vodă and Radu[11] highlight how AI can support the transition to renewable energy by regulating the balance between supply and demand. Through machine learning algorithms, AI helps optimize the use of renewable energy sources such as solar or wind power for the lighting of public spaces. This approach not only saves operational costs, but also supports the city's commitment to environmental sustainability.

Nikitas et al.[12] added that the application of Urban Artificial Intelligence emphasizes the importance of system autonomy in managing city energy. In other words, AI-powered public spaces do not just rely on human intervention, but are able to adapt independently to changing conditions. This creates a truly smart and responsive public space, while strengthening the city's resilience to future challenges. Precedent studies show that the use of AI in the energy efficiency of public spaces provides a dual benefit: improving the quality of services for citizens while reducing the environmental burden. By optimizing lighting, energy distribution, and renewable energy integration, AI plays a critical role in realizing adaptive, efficient, and sustainable urban public spaces.

[11] Ana Iolanda Vodă and Laura-Diana Radu. "Artificial intelligence and the future of smart cities." *BRAIN. Broad Research in Artificial Intelligence and Neuroscience* 9, no. 2 (2018): 110–19.

[12] Alexandros Nikitas, Kalliopi Michalakopoulou, Eric Tchouamou Njoya, and Dimitris Karampatzakis. "Artificial intelligence, transport and the smart city: Definitions and dimensions of a new mobility era." *Sustainability* 12, no. 7 (2020): 2789.

4.2. Citizens' Experience and Interaction in Public Spaces

The application of Artificial Intelligence (AI) in urban public spaces is not only related to energy efficiency, but also contributes greatly to improving citizen experience and interaction. Public space is the meeting point of various social, cultural, and economic activities, so spatial adaptivity is important to be able to meet diverse needs. With the support of AI, public spaces can be transformed into a more interactive, comfortable, and safe environment for their users. Fontes et al.[13] explained that AI-based public spaces can increase people's sense of security through intelligent surveillance systems. Sensors and cameras based on machine learning algorithms are able to detect abnormal behavior patterns and provide early warning of potential security breaches. This system has been proven to increase the comfort of residents in their activities, both during the day and at night.

In addition to the security aspect, the citizen experience is also strengthened through digital interaction provided by AI. Yigitcanlar and Cugurullo[14] emphasized that the concept of Urban AI allows citizens to interact with public spaces in a more personal way. An example of this is an AI-based interactive guide app that can help travelers explore urban spaces efficiently or provide activity recommendations based on user preferences. Suharmanto[15] added that the adaptivity of AI-based public spaces is also reflected in dynamic facility management. For example, city parks can

[13] Catarina Fontes, Ellen Hohma, Caitlin C. Corrigan, and Christoph Lütge. "AI-powered public surveillance systems: why we (might) need them and how we want them." *Technology in Society* 71 (2022): 102137.
[14] Tan Yigitcanlar and Federico Cugurullo. "The sustainability of artificial intelligence: An urbanistic viewpoint from the lens of smart and sustainable cities." *Sustainability* 12, no. 20 (2020): 8548.
[15] Praise Suharmanto. "Artificial Intelligence-Driven Innovation in Smart City." *National Scientific Symposium & Call for Paper Unindra (Simponi)* 1, no. 1 (2019): 578-589.

adjust lighting, temperature, or even a schedule of community activities based on the analysis of sensor data on the number of visitors. This makes public spaces more responsive to the actual needs of the community, while improving the quality of interaction between citizens.

Meanwhile, Golubchikov and Thornbush[16] highlight how AI is combined with robotic systems in supporting public services. AI-based robots placed in public spaces can help provide information, maintain cleanliness, or even support the mobility of vulnerable groups such as the elderly. This approach expands the definition of smart public space, from just a physical space to a technology-enabled social space. Thus, the results of the precedent study show that the application of AI in public spaces brings significant transformation to citizens' experiences and interactions. Public spaces are no longer just a gathering place, but an adaptive ecosystem that provides a sense of security, comfort, and technology-based interactive experiences. This transformation strengthens the function of public space as the foundation of modern urban social life.

4.3. Challenges and Limitations of Implementing AI in Public Spaces

Although the application of Artificial Intelligence (AI) in urban public spaces promises efficiency and improved quality of life, various challenges and limitations remain. These challenges include technical, social, ethical, and policy aspects that must be overcome so that AI implementation can run effectively and sustainably.

[16] Oleg Golubchikov and Mary Thornbush. "Artificial intelligence and robotics in smart city strategies and planned smart development." *Smart Cities* 3, no. 4 (2020): 1-12.

One of the main challenges is the availability and quality of data. Khan et al.[17] shows that AI systems require large amounts of high-quality data to produce accurate predictions. However, data collection in public spaces is often constrained by fragmentation, lack of standardization, and limited access. As a result, AI implementation has the potential to result in bias if the data used is not representative.

In addition, privacy and cybersecurity issues are a serious concern. Allam and Dhunny[18] emphasized that the use of sensors, cameras, and IoT devices in public spaces opens up opportunities for violations of citizens' privacy. The data collected by the AI is at risk of being misused if there are no clear regulations and adequate legal protection. This requires a balance between the use of technology and the protection of individual rights. Infrastructure is also an obstacle in the application of AI. Vodă and Radu[19] note that many cities, especially in developing countries, face limitations in terms of digital infrastructure and smart energy networks. Without strong infrastructure support, AI technology is difficult to function optimally in public spaces. This challenge requires major investment and cross-sectoral cooperation, including government, the private sector, and society.

[17] Sulaiman Khan, Shah Nazir, Iván García-Magariño, and Anwar Hussain. "Deep learning-based urban big data fusion in smart cities: Towards traffic monitoring and flow-preserving fusion." *Computers & Electrical Engineering* 89 (2021): 106906.
[18] Zaheer Allam and Zaynah A. Dhunny. "On big data, artificial intelligence and smart cities." *Cities* 89 (2019): 80-91.
[19] Ana Iolanda Vodă and Laura-Diana Radu. "Artificial intelligence and the future of smart cities." *BRAIN. Broad Research in Artificial Intelligence and Neuroscience* 9, no. 2 (2018): 110–19.

On the other hand, there are also social and ethical challenges. Cugurullo[20] underlined that the presence of Urban AI can trigger dependence on technology and reduce the role of citizens in the decision-making process. Unequal access to technology can also widen social gaps, where only a small number of groups can fully benefit from smart public spaces. Therefore, AI-based public space design must pay attention to inclusivity in order to serve all levels of society. With these challenges in mind, it's clear that the application of AI in the public space requires a holistic strategy that focuses not only on technology, but also on regulations, infrastructure, and social aspects. Without this, the potential of AI in realizing smart and adaptive urban public spaces will not be optimally achieved.

5. Discussion

The results of this study show that the application of Artificial Intelligence (AI) in the development of urban public spaces makes a real contribution to creating an adaptive, efficient, and sustainable smart city. The three main aspects found in the precedent study include energy management, improving citizen experience, and implementation challenges. Each of these aspects shows how AI can be a catalyst for the transformation of public spaces, while underscoring the need for comprehensive policies to address its limitations.

First, in terms of energy efficiency, AI has been proven to be able to optimize the distribution of public resources, such as lighting and the use of renewable energy.

[20] Federico Cugurullo. "Urban artificial intelligence: From automation to autonomy in the smart city." *Frontiers in Sustainable Cities* 2 (2020): 38.

The application of adaptive lighting in urban parks, for example, provides a dual benefit: reducing energy consumption while improving safety. This is in line with the view of Ortega-Fernández et al.[21] that smart cities need the integration of smart technologies to support sustainability. Therefore, AI-based energy management must continue to be strengthened through investment in digital infrastructure and energy sustainability programs.

Second, in terms of citizen experiences and interactions, AI contributes to the improvement of the comfort and safety of public spaces. Algorithm-based surveillance systems can detect threats faster, while interactive guide apps support personalized experiences for residents and tourists alike. According to Yigitcanlar and Cugurullo[22] this phenomenon illustrates the birth of the concept of Urban AI, where cities not only use technology as tools, but also present an environment that is able to "interact" with its citizens. These findings indicate that smart public spaces can strengthen social cohesion while expanding access to innovative public services.

However, the results of the study also confirm that there are major challenges that should not be ignored. The availability of adequate data, privacy issues, and limited infrastructure are the main obstacles to the application of AI in public spaces. Batty[23] highlights that without strong legal protections, citizens' data is at risk of being used for unethical purposes. In addition, social disparities can widen even

[21] Anabel Ortega-Fernández, Rodrigo Martín-Rojas, and Víctor Jesús García-Morales. "Artificial intelligence in the urban environment: Smart cities as models for developing innovation and sustainability." *Sustainability* 12, no. 19 (2020): 7860.

[22] Tan Yigitcanlar and Federico Cugurullo. "The sustainability of artificial intelligence: An urbanistic viewpoint from the lens of smart and sustainable cities." *Sustainability* 12, no. 20 (2020): 8548.

[23] Michael Batty. "Artificial intelligence and smart cities." *Environment and Planning B: Urban Analytics and City Science* 45, no. 1 (2018): 3-6.

more if only some groups of people are able to access the benefits of smart public spaces. Therefore, a collaborative approach between government, the private sector, and civil society is needed to ensure the adoption of AI is inclusive and equitable.

This discussion also emphasized the need for a new paradigm in urban planning. Instead of simply adopting technology, cities should develop data governance policies, ethics for the use of AI, and digital literacy programs for their citizens. This approach will ensure that the transformation of AI-based public spaces is not only technocratic, but also democratic, by placing citizens at the center of smart city development. Thus, AI can truly serve as a tool to improve the quality of life of all citizens, not just an elite technology that reinforces inequality. This discussion confirmed that while AI has great potential in the development of intelligent public spaces, the success of its implementation depends heavily on the synergy between technology, policy, and society. Multi-sector collaboration, clear regulations, and attention to social and ethical aspects are key for smart public spaces to truly be the foundation of an inclusive, adaptive, and sustainable future city.

6. Conclusion

This research emphasizes that the application of Artificial Intelligence (AI) in the development of urban public spaces is a strategic step to realize an adaptive, efficient, and sustainable smart city. The results of the study show that AI plays an important role in three main aspects, namely energy management efficiency, improved citizen experience and interaction, and implementation challenges that include data, privacy, infrastructure, and social aspects. In terms of energy

management, AI helps optimize the use of resources so that public spaces can operate more economically and environmentally friendly.

In terms of citizen experience, AI enables the creation of safe, comfortable, and interactive public spaces through the use of sensors, intelligent surveillance systems, and adaptive public service applications. Meanwhile, the challenges identified require cross-sector collaboration and clear regulations so that the use of technology can run in a fair and inclusive manner. Thus, this research makes a contribution both theoretically and practically in understanding the role of AI for urban public spaces. It is hoped that these findings can be a foundation for the government, academics, and the community in designing smart city development policies and strategies in the future.

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Yigitcanlar, Tan, and Federico Cugurullo. "The sustainability of artificial intelligence: An urbanistic viewpoint from the lens of smart and sustainable cities." *Sustainability* 12, no. 20 (2020): 8548.