



Blockchain Meets Edge Intelligence for Smart Cities Sustainability: An Insightful Review and Prospective Analysis

Mustafa El-Taie ^{1,*}, Aaras Y.Kraidi ²

¹ Digital Charging Solutions GmbH, Germany

² University of Technology and Applied Science, Shinas, Oman
Emails: Mustafa.iessa@gmail.com; aaras.kraidi@shct.edu.om

Abstract

The convergence of blockchain technology and edge intelligence has emerged as a transformative force in the realm of smart cities, offering unprecedented opportunities to enhance sustainability. This paper presents a comprehensive review and prospective analysis of this convergence, shedding light on its potential to revolutionize urban environments. We commence with an exploration of the fundamental components of blockchain technology, emphasizing its core principles of decentralization, immutability, and consensus mechanisms. Simultaneously, we trace the historical evolution of blockchain from its origins with Bitcoin to its broad applications in diverse domains. In the context of edge intelligence, we examine how this paradigm shift decentralizes data processing, enabling real-time decision-making and enhancing data security. We elucidate its key components, such as edge devices and analytics algorithms, while highlighting its critical role in reshaping the urban landscape. The crux of this paper lies in the convergence of blockchain and edge intelligence, where we explore its profound implications for the sustainability of smart cities. From efficient energy management and waste reduction to improved transportation and green infrastructure, this convergence empowers smart cities to optimize resource usage, reduce environmental impact, and enhance the quality of life for their residents. Through a prospective analysis, we anticipate emerging trends and innovations that will shape the future of smart city sustainability, including AI integration, 5G connectivity, and circular economy initiatives. As smart cities continue to evolve, they stand at the forefront of addressing urbanization challenges while fostering sustainable, inclusive, and prosperous urban environments.

Keywords: Blockchain; Edge intelligence; Smart cities; Sustainability; Urban development; Environmental impact; Civic engagement.

1. Introduction

Smart cities represent the cutting edge of urban development in the 21st century. These cities leverage technology and data-driven solutions to enhance the quality of life for their residents while addressing the complex challenges posed by rapid urbanization. The idea behind smart cities is not merely to embrace technology for its own sake but to harness its power to make urban environments more sustainable, efficient, and livable. As the world becomes increasingly urbanized, the significance of smart city initiatives becomes all the more pronounced. The need for sustainable urban development has never been more pressing [1]. The modern world faces unprecedented environmental challenges, from climate change and resource depletion to air pollution and overpopulation. Cities are at the forefront of these challenges, accounting for a significant portion of global energy consumption and greenhouse gas emissions. As urban populations continue to grow, it is imperative that cities prioritize sustainability to mitigate their environmental impact and improve the well-being of their residents [2].

The transformation of cities into smart, sustainable ecosystems hinges on the integration of emerging technologies. Among these, blockchain and edge intelligence have emerged as powerful tools with the potential to reshape urban landscapes. Blockchain, with its decentralized ledger technology, promises secure and transparent data management, while edge intelligence offers real-time data processing and decision-making capabilities at the edge of the network.

These technologies are poised to play a pivotal role in the evolution of smart cities, driving innovation in various sectors [3].

Blockchain technology, initially designed as the underlying infrastructure for cryptocurrencies, has evolved into a versatile tool with applications spanning finance, supply chain management, healthcare, and beyond. At its core, blockchain is a distributed ledger that ensures data integrity and transparency through consensus mechanisms [4]. This revolutionary technology has the potential to transform how cities manage data, enforce contracts, and enhance trust among stakeholders. Its decentralized nature challenges traditional centralized systems, offering new avenues for secure and efficient data management [5].

Edge intelligence represents a paradigm shift in data processing and analytics. In a world where data is generated at an unprecedented pace, the ability to make real-time decisions at the network's edge is invaluable. Edge intelligence moves computation closer to data sources, reducing latency and enabling more responsive systems [6]. Within the context of smart cities, this capability translates into improved efficiency, enhanced public safety, and a more robust infrastructure capable of adapting to dynamic urban environments. While considerable research has explored the individual applications of blockchain and edge intelligence, there remains a notable gap in the literature concerning their integrated use for advancing smart city sustainability. Existing studies often focus on singular technologies or lack a comprehensive review of their combined potential in the context of smart urban development. This paper seeks to bridge this gap by providing a comprehensive review and prospective analysis of how the convergence of blockchain and edge intelligence can offer innovative solutions to the complex challenges faced by modern cities [7]. The primary objective of this paper is to offer an insightful review of the integration of blockchain and edge intelligence as key enablers for enhancing the sustainability of smart cities. Additionally, we aim to provide a prospective analysis of the future developments and potential challenges in this exciting intersection of technology and urban planning. By offering a comprehensive overview and critical analysis, this paper serves as a valuable resource for researchers, policymakers, and practitioners interested in the future of smart city development [8].

This paper is structured to provide a comprehensive exploration of the integration of blockchain and edge intelligence for enhancing the sustainability of smart cities. In order to provide a clear roadmap for our readers, we have organized the paper into several distinct sections, as summarized in Table 1: Paper Organization. This structured approach enables us to systematically explore the integration of blockchain and edge intelligence for enhancing smart city sustainability.

Table 1: Paper Organization

Section	Description
1. Background and Context	Setting the stage for the paper and highlighting urban challenges.
2. Blockchain Technology	In-depth exploration of blockchain technology and its principles.
3. Edge Intelligence	Explanation of edge intelligence and its role in smart cities.
4. Convergence of Blockchain and Edge Intelligence	Discussion of the synergy between these technologies.
5. Applications and Case Studies	Real-world examples showcasing integration in smart cities.
6. Prospective Analysis	Future outlook, challenges, and recommendations.
7. Conclusion	Summarizing key points and paper significance.

2. Background and Context

Smart cities represent a transformative approach to urban development, harnessing the power of technology and data-driven solutions to optimize resources, enhance services, and improve the quality of life for their residents. In essence, a smart city is a urban environment that integrates various digital technologies to efficiently manage its assets, resources, and services. Unlike traditional urban areas, which often rely on conventional infrastructure and systems, smart cities employ a holistic, data-centric approach to address the challenges of urbanization [9]. Smart cities are characterized by a distinct set of key features that set them apart from traditional urban areas. These characteristics, illustrated in Table 1 below, underscore the innovative and forward-thinking nature of smart city initiatives. One of the hallmark traits is the seamless integration of technology into all aspects of urban life. This enables data-driven

decision-making, where real-time information is utilized to optimize city services and resources. Additionally, smart cities prioritize sustainability through practices that reduce environmental impact and promote resource efficiency. These cities are also committed to improving the quality of life for residents by providing enhanced services, from efficient transportation networks to digital governance platforms [10]. Table 2 provides a comprehensive comparison between smart cities and traditional urban areas across various key characteristics. It highlights the fundamental differences in how these two urban paradigms approach technology integration, resource management, sustainability practices, the quality of life for residents, infrastructure resilience, and citizen engagement

Table 2: Comparison between Smart Cities and Traditional Urban Areas

Characteristic	Smart Cities	Traditional Urban Areas
Technology Integration	Seamless integration of technology and data for efficient management and decision-making.	Reliance on conventional infrastructure and systems with limited technology integration.
Data-Driven Decision-Making	Extensive use of data analytics and real-time information for urban planning and resource optimization.	Limited utilization of data-driven approaches for decision-making.
Resource Efficiency	Optimal allocation and utilization of resources, including water, energy, and transportation.	Often faces challenges in resource management, leading to inefficiencies.
Sustainable Practices	Emphasis on sustainability with green initiatives, reducing environmental impact and promoting eco-friendly solutions.	May lack comprehensive sustainability practices, leading to higher environmental impact.
Improved Quality of Life	Enhanced services and amenities for residents, including efficient transportation, healthcare, and digital governance.	May offer basic services but often lacks advanced amenities and efficient services.
Infrastructure Resilience	Resilient infrastructure with systems in place for disaster preparedness and quick recovery.	Vulnerable to natural disasters with less resilience built into infrastructure.
Citizen Engagement	Encourages active citizen participation through digital platforms and feedback mechanisms.	Limited mechanisms for citizen engagement and participation in decision-making.

Urbanization is a defining global trend of the 21st century, reshaping the human landscape as populations increasingly gravitate toward urban areas. The magnitude of this phenomenon is nothing short of profound, as millions of people seek better opportunities, improved living conditions, and access to essential services in cities. The ongoing migration from rural to urban areas represents a fundamental shift in how societies are structured and economies are driven. This trend is not restricted to a single region or continent; it transcends borders and cultures, making it one of the most significant demographic shifts in human history. The consequences of this urbanization wave are vast, encompassing challenges and opportunities related to infrastructure development, resource management, and the well-being of city dwellers [11].

To grasp the scale of urbanization, it is essential to examine the statistics and data that highlight its magnitude. As of 2022, more than 57 % of the global population resides in urban areas. By 2050, it is projected that 70% of the world's population will call cities home, with the pace of urbanization showing no signs of deceleration. The sheer numbers involved in this shift are staggering, as hundreds of millions of individuals continue to move to urban centers each year. In Figure 1 below, we provide a breakdown of urbanization trends by region, illustrating how different parts of the world are experiencing varying degrees of urban growth. This data underscores the urgency of addressing urban

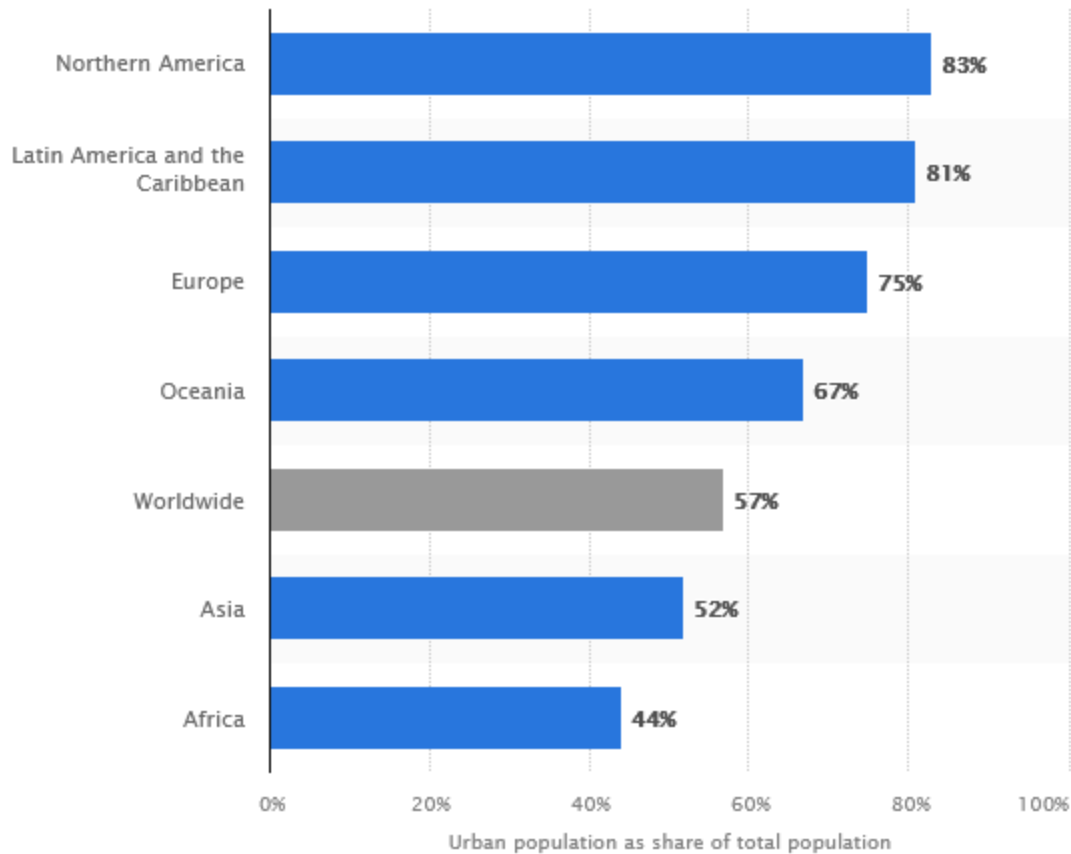


Figure 1: Urbanization Trends by Region (as of 2022)

challenges and the need for innovative solutions to ensure that urbanization enhances, rather than diminishes, the quality of life for billions of city residents.

These statistics offer a glimpse into the immense scale and pace of urbanization worldwide, highlighting the need for strategic urban planning and innovative approaches to address the challenges and opportunities it presents.

Modern cities navigate a complex web of challenges as they grapple with the multifaceted demands of urbanization. One of the foremost challenges is transportation, marked by escalating traffic congestion, inadequate public transit systems, and inefficient transportation networks. These issues not only lead to productivity losses but also contribute to environmental degradation through increased emissions. Energy consumption poses another significant challenge, with the growing urban population placing heightened demands on energy resources. Meeting the energy needs of cities sustainably while reducing greenhouse gas emissions remains a formidable task. Additionally, pollution levels, encompassing air, water, and noise pollution, are on the rise, impacting the health and well-being of urban residents. Lastly, effective resource management, including water and waste management, is a perpetual concern, as cities must balance resource availability with growing demands [12].

The challenges modern cities face bear profound social and environmental implications that reverberate through the fabric of urban life. Transportation challenges, for instance, lead to longer commutes, reduced quality of life, and increased stress levels for city dwellers. They also contribute to air pollution, which can lead to respiratory illnesses and other health issues. Furthermore, inefficient transportation networks can perpetuate social inequalities, as

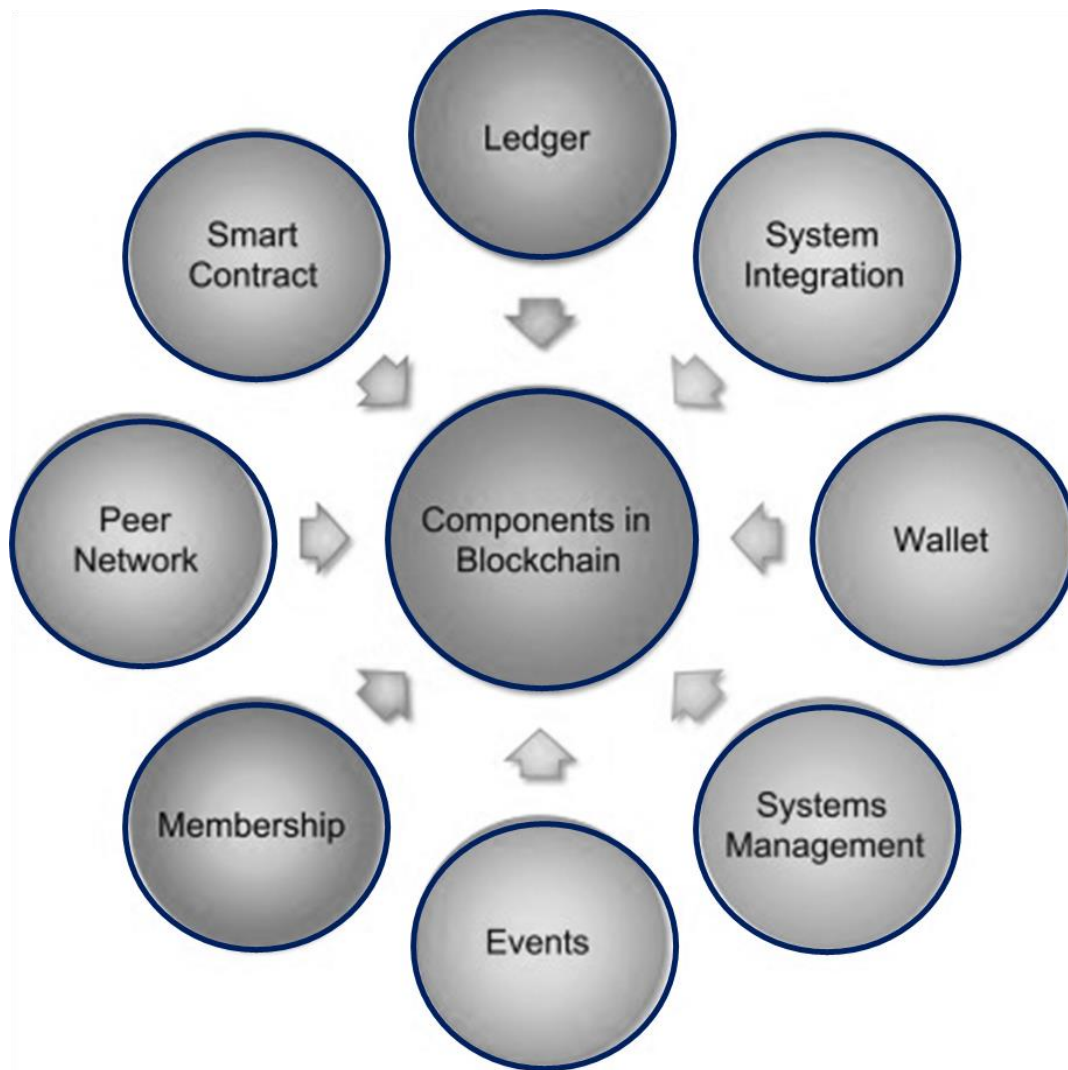


Figure 2: Fundamental Components of a Blockchain

marginalized communities may face limited access to jobs and services [13]. Energy consumption and its environmental ramifications are equally pressing, as higher energy demands intensify greenhouse gas emissions, exacerbating climate change and its associated consequences. Pollution, whether it's air pollution from vehicle emissions or water pollution from industrial runoff, jeopardizes both human health and the environment, necessitating costly remediation efforts. Inefficient resource management, including water scarcity and waste mismanagement, strains urban ecosystems, leading to resource depletion and environmental degradation. Addressing these challenges requires holistic and innovative solutions that not only mitigate their social and environmental impacts but also enhance the resilience and livability of modern cities [14].

A blockchain comprises several fundamental components that collectively form the architecture of this revolutionary technology. These components include blocks, transactions, cryptographic hashing, and the blockchain ledger, as depicted in Figure 2. Each block within the blockchain contains a collection of transactions, which are records of data exchanges. These transactions can represent various types of data or digital assets, depending on the specific use case of the blockchain [15]. To maintain the integrity and security of the data, each block contains a unique identifier known as a cryptographic hash, generated through complex mathematical algorithms. The blockchain ledger is the distributed and decentralized database that stores all these blocks, ensuring that data is replicated across multiple nodes within the network. Together, these components create a robust and tamper-proof structure where data is recorded and secured with unparalleled transparency and immutability [16].

The fundamental components of a blockchain work in concert to guarantee data integrity and security throughout the network. To illustrate this process, consider how transactions are recorded and added to the blockchain. When a participant initiates a transaction, it is broadcast to the network and collected with other pending transactions into a block. Once the block reaches a certain size or a time interval passes, it is sealed with a cryptographic hash that includes the information from the previous block. This interlinking of blocks ensures that any tampering with the data within a block would alter the hash, setting off alarms within the network [17].

3. Blockchain Technology

Blockchain technology is a decentralized and distributed ledger system that underpins cryptocurrencies like Bitcoin while extending its utility to a wide array of applications beyond digital currencies. At its core, blockchain is a digital ledger that records transactions across multiple computers in a way that ensures transparency, security, and immutability. The three key principles that form the foundation of blockchain technology are decentralization, immutability, and consensus mechanisms. Firstly, decentralization means that there is no central authority governing the blockchain network. Instead, data is stored on a network of computers (nodes) that collectively maintain and validate the ledger. This decentralization ensures that no single entity has control over the system, enhancing transparency and reducing the risk of censorship or manipulation [18]. Secondly, immutability is a fundamental feature of blockchain technology. Once data is recorded in a block and added to the chain, it becomes nearly impossible to alter or delete. Each block contains a cryptographic reference to the previous block, creating a chain of blocks that are interlinked and secured through complex algorithms. This immutability enhances the trustworthiness of the data and makes blockchain suitable for applications where data integrity is critical. Lastly, consensus mechanisms are protocols that enable network participants to agree on the state of the blockchain. These mechanisms ensure that all nodes in the network reach a consensus on the validity of transactions and the order in which they are added to the ledger. Common consensus mechanisms include Proof of Work (PoW) and Proof of Stake (PoS), each with its own approach to achieving agreement within the network [19].

The genesis of blockchain technology can be traced back to 2008 when an individual or group operating under the pseudonym Satoshi Nakamoto introduced Bitcoin, the first cryptocurrency. Bitcoin's primary innovation was its use of blockchain as a public ledger to record all transactions. Bitcoin's success laid the foundation for the broader adoption of blockchain technology [20]. Over time, blockchain technology has evolved beyond cryptocurrencies and gained recognition for its potential in various domains. Early blockchain applications primarily focused on financial transactions and digital currencies. However, the technology's inherent security, transparency, and decentralization qualities soon attracted interest from industries such as supply chain management, healthcare, voting systems, and more. Today, blockchain is recognized as a transformative technology with applications ranging from smart contracts and digital identity to supply chain traceability and decentralized finance (DeFi). Its history and evolution reflect the continuous innovation and adaptation of blockchain technology to address diverse challenges and opportunities across various sectors, including its emerging role in advancing sustainability and efficiency in smart city development [21].

Blockchains can be categorized into several main types based on their accessibility, control, and usage scenarios (See Table 3). The primary types of blockchains are public, private, and consortium (also known as federated) blockchains.

- a. **Public Blockchains:** Public blockchains are open and permissionless networks that allow anyone to participate, read, and write data to the blockchain without needing approval. These blockchains, such as Bitcoin and Ethereum, are maintained by a decentralized network of nodes worldwide. They provide a high level of transparency and security but may have scalability challenges due to their open nature [22].
- b. **Private Blockchains:** Private blockchains, in contrast, are restricted and permissioned networks where participation and access are controlled. These blockchains are often used within organizations or consortia of organizations. They offer greater control over who can join the network and what data is visible, making them suitable for applications where privacy and compliance are crucial.
- c. **Consortium Blockchains:** Consortium blockchains strike a balance between public and private blockchains. They are governed by a predefined group of organizations or entities, allowing for greater control and efficiency than public blockchains while maintaining a degree of decentralization. Consortium blockchains are well-suited for collaborative efforts among multiple entities, such as industry-specific use cases or supply chain management [23].

Table 3: Differentiating Characteristics of Public, Private, and Consortium Blockchains

Characteristic	Public Blockchain	Private Blockchain	Consortium Blockchain
Accessibility	Open to anyone	Restricted access	Controlled access
Permissionless	Yes	No	No
Governance	Decentralized	Centralized or decentralized	Governed by a group
Transparency	High	Variable	Variable
Privacy	Limited	High	Balance of privacy and transparency
Use Cases	Cryptocurrencies, decentralized applications	Enterprise use cases, internal processes	Collaborative industry efforts, supply chain management
Scalability	Challenges due to open access	Scalability depends on network design	Scalability depends on network design
Examples	Bitcoin, Ethereum	Hyperledger Corda	Fabric, R3 Corda, Hyperledger Consortiums

4. Edge Intelligence

Edge intelligence, often referred to as edge computing, is a pivotal technological paradigm that holds immense promise for enhancing the efficiency and responsiveness of smart cities. At its core, edge intelligence decentralizes data processing and computation, pushing these functions closer to the data source, which is often at the edge of the network—hence the term "edge." This shift in data processing architecture is a direct response to the increasing volume of data generated by IoT devices and the need for real-time decision-making [24]. In smart cities, where vast arrays of sensors, cameras, and connected devices continuously collect data, edge intelligence provides a means to process and analyze this data locally. By doing so, it reduces latency, enhances data privacy, and minimizes the need for extensive data transmission to centralized cloud servers. This decentralized approach empowers smart cities to make swift, data-informed decisions, optimize resource allocation, and improve the overall quality of urban services [25].

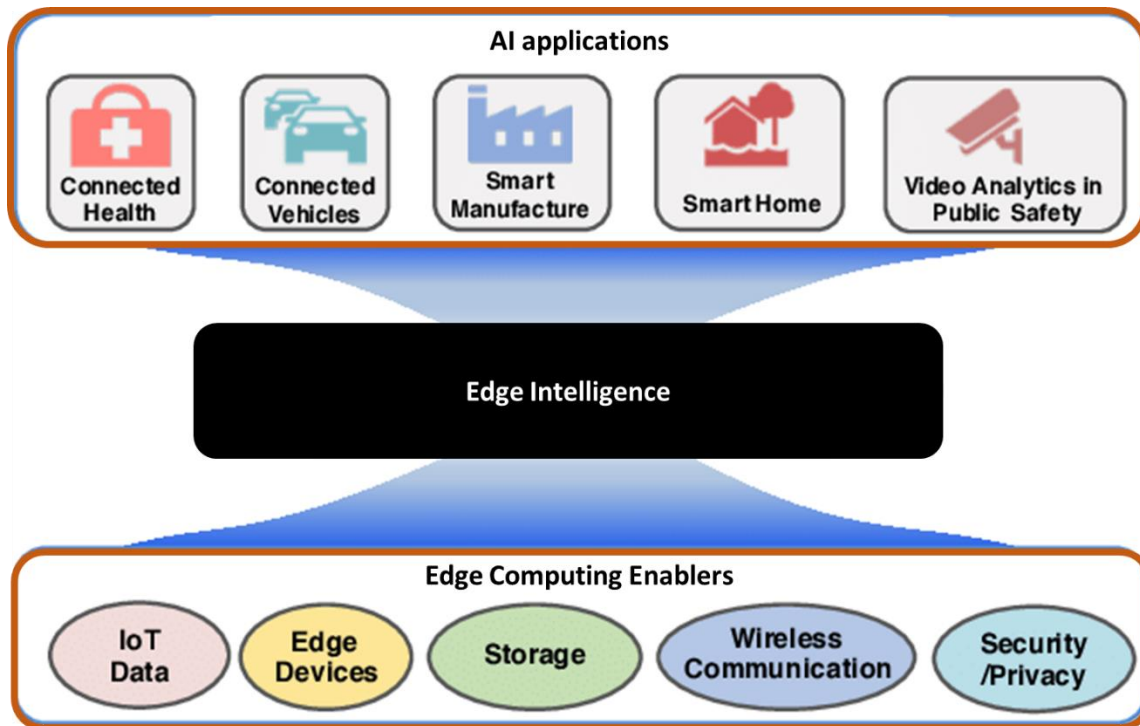


Figure 3: Fundamental Components of Edge intelligence

Edge intelligence comprises a set of key components and associated benefits that are vital for its successful implementation in smart city environments. These components typically include edge devices (sensors, actuators, etc.), edge computing infrastructure, and edge analytics algorithms. Edge devices collect data from various sources, while edge computing infrastructure processes and analyzes this data locally. Edge analytics algorithms play a crucial role in extracting valuable insights and patterns from the data, enabling real-time decision-making [20]. The advantages of edge intelligence in smart cities are multifaceted. Firstly, it significantly reduces data transfer and storage costs by processing data closer to its source, alleviating network congestion and reducing the strain on centralized cloud servers. Secondly, edge intelligence enhances data security and privacy, as sensitive information can be processed locally, reducing the risk of data breaches during transmission. Thirdly, it enables low-latency responses, critical for applications like autonomous vehicles, smart grids, and emergency response systems. Ultimately, edge intelligence contributes to the agility and sustainability of smart cities, paving the way for more efficient resource allocation and improved urban living standards [22].

5. Convergence of Blockchain and Edge Intelligence

The convergence of blockchain and edge intelligence marks a pivotal turning point in the development of smart cities, offering the potential to significantly enhance sustainability. Smart cities aim to optimize resource usage, reduce environmental impact, and improve the quality of life for their residents. However, achieving these objectives in a rapidly urbanizing world poses significant challenges [21]. The integration of blockchain technology, with its transparency, security, and decentralized nature, and edge intelligence, which enables real-time data processing and analytics at the edge of the network, creates a powerful synergy. This synergy empowers smart cities to enhance their sustainability efforts across various domains, including energy management, waste reduction, transportation, and more [26].

One of the primary ways in which the convergence of blockchain and edge intelligence contributes to smart city sustainability is through enhanced energy management and efficiency. Smart cities often grapple with the need to reduce energy consumption and carbon emissions while meeting the increasing energy demands of a growing population [27]. The integration of edge devices equipped with sensors and real-time monitoring capabilities enables fine-grained energy management at the local level. These devices can collect data on energy usage and environmental conditions, facilitating real-time adjustments to energy distribution and consumption. Blockchain technology ensures

transparent and secure energy transactions among various stakeholders, such as consumers, producers, and grid operators. Smart contracts on the blockchain can automate energy trading, incentivize energy-efficient behaviors, and even enable the integration of renewable energy sources. This not only reduces energy waste but also promotes the use of sustainable energy, contributing to a greener and more resilient urban landscape [28].

Another critical aspect of smart city sustainability is waste management and the promotion of a circular economy. The convergence of blockchain and edge intelligence can revolutionize how cities handle waste by enabling real-time monitoring and tracking of waste streams. Smart bins equipped with sensors can detect fill levels and environmental conditions, optimizing waste collection routes and schedules. Moreover, blockchain's transparency and traceability enable the creation of a tamper-proof record of waste disposal and recycling activities [29]. This can incentivize responsible waste disposal practices and promote recycling by providing rewards or tokens on the blockchain for proper disposal. Additionally, blockchain-powered platforms can facilitate the sharing and reuse of resources and materials among businesses and residents, reducing waste generation and promoting a more sustainable circular economy. This convergence not only reduces the environmental footprint of cities but also enhances their resilience in managing waste-related challenges [30].

6. Applications and Case Studies

Smart cities worldwide have embraced sustainability as a core principle, leveraging advanced technologies to address urban challenges while promoting environmental stewardship and social equity. A multitude of innovative applications have emerged, showcasing the potential of smart city initiatives to drive sustainability. These applications span diverse domains, from energy management and waste reduction to transportation optimization and green infrastructure development [21]. One notable example is the implementation of smart grids that use blockchain and edge intelligence to efficiently distribute renewable energy, reducing carbon emissions and promoting cleaner power sources. Similarly, smart waste management systems employ sensors and data analytics to optimize collection routes, reducing fuel consumption and minimizing the environmental impact of waste disposal. Additionally, smart transportation solutions, including real-time traffic management and autonomous vehicles, enhance mobility while reducing congestion and emissions. These applications represent just a glimpse of the transformative potential of sustainability-driven smart city initiatives, underscoring the importance of technology in shaping urban environments for the future [25]. Table 4 provides an overview of current applications in the sustainability of smart cities. These applications leverage advanced technologies to address urban challenges and promote environmental stewardship, ultimately enhancing the quality of life for city residents.

Table 4: Overview of Diverse Applications Advancing Sustainability in Smart Cities

Application Area	Description	Technology Used	Sustainability Impact
Smart Grids	Efficient energy distribution using blockchain and edge intelligence	Blockchain, IoT, Edge Computing	Reduced carbon emissions, increased renewable energy use
Smart Waste Management	Optimized waste collection and recycling	IoT, Data Analytics	Reduced waste, lower fuel consumption
Smart Transportation	Real-time traffic management and autonomous vehicles	IoT, AI, Edge Computing	Reduced congestion, lower emissions
Green Infrastructure	Sustainable urban planning and green space development	GIS, IoT	Improved urban greenery, air quality, and livability
Water Management	Efficient water usage and leakage detection	IoT, Data Analytics	Reduced water waste and conservation
Digital Governance	Citizen engagement and data-driven decision-making	Blockchain, AI	Enhanced transparency, better governance
Environmental Monitoring	Real-time air quality and pollution monitoring	IoT, Sensors	Improved public health, reduced pollution
Smart Buildings	Energy-efficient building management	IoT, Building Automation	Lower energy consumption, reduced carbon footprint
Urban Mobility	Sustainable and shared transportation solutions	Mobility-as-a-Service, IoT	Reduced traffic, lower emissions, improved mobility
Renewable Energy	Integration of renewable energy sources	Solar, Wind, Energy Storage	Increased use of clean energy sources

Smart Agriculture	Precision farming and sustainable agriculture practices	IoT, AI	Increased agricultural efficiency, reduced resource use
Waste-to-Energy Conversion	Converting waste into energy sources	Waste-to-Energy Technology	Reduced landfill waste, clean energy production
Public Safety and Security	Advanced surveillance and emergency response systems	AI, IoT	Enhanced safety, reduced response times
Healthcare	Telemedicine, remote health monitoring	IoT, Telehealth Technology	Improved access to healthcare, reduced healthcare costs

7. Prospective Analysis

As smart cities continue to evolve and expand their horizons, it is imperative to undertake a prospective analysis that explores the future trends and potential developments in the realm of sustainability. While the current applications and initiatives in smart city sustainability are impressive, they represent just the beginning of a transformative journey [10]. Looking ahead, there is a range of key factors and emerging trends that will shape the trajectory of sustainable smart cities. One of these factors is the increasing integration of AI and machine learning, which will enhance data analytics capabilities for more precise decision-making. Additionally, the advent of 5G and the IoT will usher in an era of seamless connectivity, enabling real-time data exchange and more responsive urban systems. Moreover, the continued growth of blockchain technology may lead to the tokenization of sustainable actions, incentivizing residents and organizations to actively participate in sustainability efforts [14]. By exploring these and other prospective trends, we aim to provide valuable insights into the future of smart city sustainability and its potential to create more resilient, efficient, and eco-conscious urban environments. Table 5 provides a comprehensive prospective analysis of emerging trends in the sustainability of smart cities. These trends encompass a wide range of domains, from advanced technologies to innovative urban planning, offering insights into the future of sustainable urban environments.

Table 5: Prospective Analysis of Emerging Trends in Smart City Sustainability

Trend	Description	Potential Impact	Challenges and Considerations	Key Players and Innovations
AI and Machine Learning Integration	Enhanced data analytics, predictive modeling, and automation of sustainable practices.	More precise decision-making, resource optimization.	Data privacy, ethical AI use.	IBM Watson, Google AI, Microsoft Azure
5G and IoT Connectivity	Seamless real-time data exchange, improved connectivity for IoT devices, and smart infrastructure.	Enhanced responsiveness, more efficient systems.	Network security, infrastructure costs.	Huawei, Ericsson, Qualcomm
Blockchain Tokenization	Incentivizing sustainability actions through blockchain-based tokens and rewards.	Increased community engagement, participation.	Regulatory and legal challenges.	Ethereum, VeChain, Algorand
Renewable Energy Integration	Wider adoption of renewable energy sources and decentralized energy generation.	Reduced carbon emissions, increased resilience.	Energy storage and grid integration.	Tesla, Siemens, SolarCity
Circular Economy Initiatives	Promoting resource recycling, reduced waste, and sustainable product lifecycles.	Resource conservation, waste reduction.	Supply chain complexities.	Ellen MacArthur Foundation, TerraCycle
Smart Mobility Solutions	Advanced mobility options, autonomous vehicles, and efficient transportation systems.	Reduced congestion, lower emissions.	Infrastructure development.	Waymo, Tesla, Uber

Green Building Technologies	Sustainable construction materials, energy-efficient designs, and smart building management.	Lower energy consumption, reduced environmental impact.	Cost of green building technologies.	Schneider Electric, Honeywell, Johnson Controls
Resilience Planning	Climate adaptation strategies, disaster response systems, and urban resilience planning.	Enhanced preparedness, reduced vulnerability.	Funding and implementation challenges.	The Rockefeller Foundation, UNDRR
Urban Agriculture	Vertical farming, rooftop gardens, and community gardens to promote local food production.	Reduced food miles, increased food security.	Land use and zoning regulations.	AeroFarms, Gotham Greens, Freight Farms
Sustainable Water Management	Advanced water purification technologies, efficient distribution, and smart water infrastructure.	Improved water quality, reduced water waste.	Aging water infrastructure, water scarcity.	Suez, Veolia, Xylem

8. Conclusions

This work delved into the dynamic intersection of blockchain technology, edge intelligence, and their profound implications for the sustainability of smart cities. Through a comprehensive exploration of these technological advancements, we have illuminated their potential to revolutionize urban landscapes. The amalgamation of blockchain's transparent and secure data management, edge intelligence's real-time processing capabilities, and their convergence offer a promising path toward creating more resilient, efficient, and eco-conscious smart cities. As we peer into the future, it becomes evident that the journey toward sustainable smart cities is an evolving narrative, shaped by continuous innovation and adaptation. The emerging trends outlined in our prospective analysis paint a picture of urban environments that are increasingly responsive, eco-friendly, and community centric. However, it is imperative to recognize that this transformation requires collaborative efforts across sectors, including government, industry, and academia. By harnessing the potential of blockchain, edge intelligence, and the forthcoming innovations, smart cities can lead the way in addressing the pressing challenges of urbanization while simultaneously fostering a sustainable, inclusive, and prosperous future for all residents.

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