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Smart Cities and Cyber-Physical Systems Integration: A Comparative Study Between Western and West African Urbanization

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Afolashade Kuyoro [1] , Folasade Ayankoya [1] , Obumneme Ukandu [1] , Samuel Okolie [1]

1. Computer Science, Babcock University, Ilishan-Remo, NGA

Corresponding author: Obumneme Ukandu, ukandu0183@pg.babcock.edu.ng

Abstract

This study compares the development and impact of smart cities and cyber-physical systems (CPS) integration in Western societies and West African urban centers, highlighting the challenges, opportunities, and disparities that shape these efforts. With rapid urbanization and unique socio-economic contexts in West Africa, the study aims to examine how smart city initiatives can address urban challenges such as inadequate infrastructure and environmental degradation. Using a scoping review methodology, the research explores the integration of technologies like IoT, AI, and data analytics, and how these are applied in both regions to enhance urban services and sustainability. The findings reveal that while Western cities have advanced smart city projects with robust technological infrastructure and governance frameworks, West African cities face infrastructure constraints and limited resources, hindering the full implementation of CPS technologies. However, there are emerging opportunities for West African cities, such as leapfrogging technology and adopting community-driven solutions. This study identifies key challenges in both regions, including data privacy concerns and governance complexities, and offers recommendations for policymakers and urban planners. The research emphasizes the need for localized approaches, capacity building, and cross-sector collaboration to promote sustainable and inclusive smart city development in West Africa, drawing on lessons from Western cities to inform future urban planning strategies.

Categories: AI applications, Energy Efficiency and Sustainability, Cyber-Physical Systems
Keywords: comparative study, cyber-physical systems (cps), internet of things, smart cities, technology integration, urbani-zation, western societies

Introduction And Background

In recent times, the notion of intelligent urban areas has risen as a hopeful approach to urban growth, utilizing sophisticated technologies to improve effectiveness, sustainability, and residents' overall well-being [1,2]. At the core of smart cities, we can find the integration of cyber-physical systems (CPS), which bridges the gap between the digital and physical worlds by connecting sensors, actuators, and computational elements to monitor and control physical entities within urban environments [3,4]. While smart city initiatives have gained significant traction in Western societies, particularly in Europe and North America, their implementation and impact in the context of West African urbanization remain relatively understudied and poorly understood [5,6].

The concept of smart cities has developed as a reaction to the difficulties presented by swift urban expansion, increasing populations, limited resources, and environmental decline [7,8]. Utilizing technologies like the Internet of Things (IoT), artificial intelligence (AI), data analytics, and connectivity solutions, smart cities strive to enhance multiple facets of urban living, encompassing transportation, energy efficiency, waste management, healthcare, and public safety [9,10]. Smart cities' key features include deploying sensor networks for real-time data collection, using predictive analytics for informed decision-making, and establishing digital frameworks for citizen participation and service delivery [8,11].

The diagram provided in Figure *1* depicts the elements of a smart city. The illustration showcases the fundamental components surrounding the city's foundational residential infrastructure. These components are depicted as a set of principles spanning various domains, such as individuals, processes, governance, mobility, environment, and enhanced living amenities like residential buildings, educational institutions, and healthcare facilities.

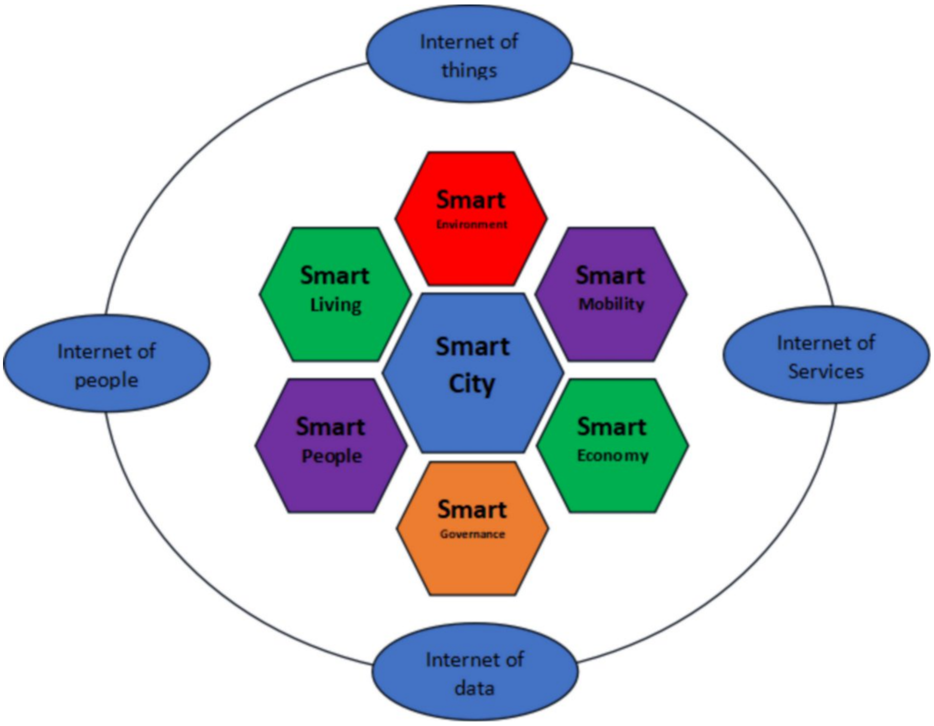

FIGURE 1: Elements of Smart City

Source: [12]

Review

Statement of the problem

While smart city initiatives hold immense potential for addressing urban challenges and fostering sustainable development, their applicability and efficacy in diverse geographical and socioeconomic contexts, such as those found in West Africa, remain unclear. West African urban centers are characterized by rapid urbanization, informal settlements, inadequate infrastructure, and socioeconomic disparities, which pose unique challenges to the application of smart city technologies. Furthermore, the extent to which CPS integration can effectively address West African cities' complex needs and realities remains a subject of debate and inquiry.

Aim and objectives

The primary aim of this comparative study is to investigate and analyze the implementation and impact of smart cities and CPS integration in both Western societies and West African urban centers. Specifically, the study objectives are as follows:

1. Compare the development and deployment of smart city initiatives in Western societies and West African urban centers.

2. Examine the integration of CPS technologies within the urban fabric of Western cities and West African urban centers.

3. Identify the key challenges, opportunities, and disparities associated with smart city development and CPS integration in both regions.

4. Extract lessons learned and best practices for successful smart city implementation that can be applied globally.

Significance of the study

This research holds importance for multiple reasons. Primarily, it adds to the expanding field of literature concerning smart cities and urban development by providing comparative perspectives on the execution and effects of smart city endeavors across various geographical and socio-cultural settings. Secondly, it sheds light on the opportunities and challenges associated with CPS integration in West African urban centers, informing policy-makers, urban planners, and stakeholders involved in urban development and technology deployment. Additionally, by highlighting best practices and lessons learned from Western experiences, the study aims to facilitate knowledge exchange and capacity-building efforts aimed at promoting sustainable and inclusive smart city solutions in West Africa.

Literature review

Definition of Smart Cities and CPS Integration

Smart cities utilize information and communication technologies (ICT) to boost the effectiveness of urban services, enhance residents' quality of life, and foster sustainable development within urban areas [13,14]. These cities integrate various technologies, including IoT devices, data analytics, AI algorithms, and communication networks, to collect, analyze, and utilize data in real-time for decision-making and resource optimization [15,16]. The idea of smart cities emphasizes the interconnectedness of physical infrastructure, digital systems, and human activities to create innovative solutions for urban challenges [17,18].

The integration of CPS is a cornerstone of smart city development, enabling the seamless interaction between physical and digital components within urban environments [19,20]. CPS refers to systems in which physical processes are monitored, controlled, and coordinated through computational algorithms and networked sensors [21]. By embedding intelligence into physical infrastructure such as transportation networks, energy grids, and public services, CPS integration enhances efficiency, resilience, and responsiveness in smart city operations [21,22].

Evolution of Smart Cities in Western Societies

The evolution of smart cities in Western societies can be traced back to the early 21st century when cities began exploring ICT solutions to address urban challenges [23,24]. Initiatives such as Amsterdam's Smart City program and Barcelona's Smart City strategy pioneered the integration of technology into urban governance, infrastructure, and service delivery [25]. Over time, Western cities have adopted a holistic approach to smart city development, focusing on sustainability, innovation, and citizen engagement.

Cities in the Western hemisphere have implemented a diverse array of technologies to enhance urban services and infrastructure, encompassing smart transportation systems, energy-efficient buildings, intelligent waste management, and digital governance platforms [26]. These initiatives have been driven by partnerships between governments, businesses, academic institutions, and community organizations, with an emphasis on collaboration, experimentation, and data-driven decision-making [26].

Urbanization Trends in West Africa

The process of rapid urbanization is underway in West Africa, characterized by a notable migration of individuals from rural to urban regions in pursuit of economic prospects and enhanced quality of life [27]. This urban growth has led to the proliferation of informal settlements, strained infrastructure, and socio-economic disparities in cities across the region. Urbanization trends in West Africa are characterized by challenges such as inadequate housing, limited access to basic services, traffic congestion, and environmental degradation [28,29].

Despite these challenges, West African cities are hubs of innovation, entrepreneurship, and cultural diversity, offering opportunities for smart city development and technological leapfrogging. Governments and international organizations are increasingly recognizing the importance of harnessing technology to resolve urban concerns and promote sustainable development in the region [27,30].

Previous Studies on CPS Integration in Smart Cities

Several studies have explored the integration of CPS in smart cities, focusing on various aspects such as technology deployment, governance models, socio-economic impacts, and policy implications. These studies have highlighted the potential benefits of CPS integration, including improved resource efficiency, enhanced public safety, and greater resilience to natural disasters. However, they have also identified challenges in this section.

Title: A Framework for Standardization of Distributed Ledger Technologies for Interoperable Data Integration and Alignment in Sustainable Smart Cities [31].

Technology Deployment: The study discusses the deployment of distributed ledger technologies (DLTs), such as blockchain, Hashgraph, Directed Acyclic Graph, Holochain, and Tempo (Radix), in urban environments.

Governance Models: The study mentions the need for a governance standard to enable different types of DLT. It also mentions the collaborative efforts of industrial alliances and standardization organizations to develop an international DLT standard and the challenges associated with achieving consensus on technical requirements and terminologies.

Socio-Economic Impacts: These impacts include facilitating interoperable services, enhancing urban operations, promoting renewable energy management, and supporting sustainable transportation systems.

Policy Implications: It discusses recommendations for DLT standardization, including the need for early standardization to assist innovation and facilitate trust, as well as the role of standards in defragmenting and coordinating disconnected initiatives within the market.

Potential Benefits of CPS Integration: The potential benefits include improved urban operations, elimination of data and value silos, enhanced coordination among stakeholders, and the promotion of business convergence. The study also highlights the opportunities presented by DLTs for resolving social problems and promoting legibility in urban environments.

Challenges Highlighted: Challenges highlighted in the article include lack of standardization, interoperability issues, and the need for alignment and integration of DLTs in smart cities. Additionally, the limitations of current DLT standards and the focus on specific DLTs, such as IOTA tangle, are mentioned, indicating the need for future research to explore interoperability among various DLTs.

Title: Account Based Ticketing (ABT) Integration for Seamless Multi-Modal Transport Systems in Smart Cities [32].

Technology Deployment: The paper emphasizes the deployment of digitalization in urban transport systems, focusing on technologies such as sensors, IoT devices, real-time data analytics platforms, and ABT systems. These technologies are seen as crucial components for enhancing efficiency, safety, and sustainability in urban mobility.

Governance Models: The governance model proposed involves collaboration between the public and private sectors to address challenges such as interoperability between different systems, cybersecurity risks, and data privacy concerns. The introduction of interoperability standards and protocols, along with partnership between stakeholders, is highlighted as essential for the effective integration of digital technologies into transport systems.

Socio-Economic Impacts: Digitalization promises more accurate traffic management, reduced congestion, increased operational efficiency in public transport, and better user satisfaction. It also mentions territorial cohesion, sustainable mobility, and operational efficiency in urban transport systems.

Policy Implications: Governments should establish interoperability standards and protocols to improve the introduction of digital technologies into transport systems. Policymakers need to invest in robust cybersecurity measures to protect transport systems from potential threats. Measures should be implemented to protect the privacy and security of user data associated with digital payment systems and travel patterns.

Potential Benefits of CPS Integration: ABT systems simplify access to public transport by discarding the need for physical tickets and allowing users to use smart cards, mobile devices, or credit cards for payment. ABT systems improve collaboration between different modes of transport, allowing users to access integrated fares and optimize their trips. ABT systems enhance user experience by providing greater flexibility, seamless access to multiple modes of transport, and personalized travel recommendations.

Challenges Highlighted: Challenges such as interoperability issues, cybersecurity risks, privacy concerns, and technical/regulatory hurdles need to be addressed for successful digital technology implementation in transport systems.

Title: Agent-Based Middleware Framework Using Distributed CPS for Improving Resource Utilization in Smart City [33].

Technology Deployment: CPS is deployed to integrate computation models and processes using a common communication platform, enabling access, data sharing, security, and service support for end-users. The study considered CPS integration in transportation systems, production industries, e-governance, and smart cities for improved reliability, scalability, stability, and interoperability.

Governance Models: The study suggest collaboration between various stakeholders for optimal resource sharing, communication, and security.

Socio-Economic Impacts: Improved resource allocation and scheduling in CPS environments contribute to reduced downtime, enhanced resource utilization, and minimized response delays, benefiting end-users and service providers.

Policy Implications: Policymakers need to focus on establishing interoperability standards, investing in cybersecurity measures, and implementing privacy protection policies to support the integration of CPS technologies in various sectors.

Potential Benefits of CPS Integration: CPS integration offers benefits such as seamless service provisioning, resource sharing, and efficient task allocation in smart cities, enhancing the overall user experience and system performance.

Challenges Highlighted: Challenges include managing interoperability issues, addressing cybersecurity risks, ensuring data privacy, overcoming technical and regulatory hurdles, and optimizing resource allocation and scheduling in distributed CPS environments.

Title: Applications of Artificial Intelligence and Machine Learning in Smart Cities [34].

Technology Deployment: The research discusses the deployment of various technologies in smart cities, including IoT, blockchain, unmanned aerial vehicles (UAVs), and advanced data analysis techniques such as AI, machine learning (ML), and deep reinforcement learning (DRL).

Governance Models: The study does not explicitly mention governance models. However, it discusses the need for regulations compatible with AI-assisted technologies and the benefits of addressing security issues in smart city applications.

Socio-Economic Impacts: The socio-economic impacts of smart cities are implied in the discussion about efficiently managing resources, optimizing energy consumption, enhancing transportation systems, improving healthcare services, and addressing security concerns.

Policy Implications: The research emphasizes the need for regulations compatible with AI-assisted technologies to ensure the smooth operation and security of smart city applications. It also mentions the importance of addressing security issues, particularly in areas like cyber-security and healthcare systems.

Potential Benefits of CPS Integration: The integration of CPS in smart cities offers numerous benefits, including efficient resource management, optimized energy consumption, improved transportation systems, enhanced healthcare services, and strengthened cyber-security measures.

Challenges Highlighted: The need for large sets of training data for ML and DRL protocols to enable accurate decision-making. Joint optimization of UAV capabilities and trajectories to improve efficiency in communication. Optimization of power-down circumstances and communication delay assessment in smart grids.

Title: UAV in Smart Cities - Integration in the Aviation System and Solutions for Safe Operations [35].

Technology Deployment: The study discusses the deployment of UAVs in smart cities for various applications such as geo-spatial and surveying activities, civil security control, traffic and crowd management, natural disaster control and monitoring, environmental management, wireless communications, commercial activities (like package deliveries), and urban air mobility.

Governance Models: The study suggests various scenarios for UAV integration into smart cities, from remotely controlled UAVs outside manned aviation airspace to fully integrated autonomous UAV swarms. Each scenario involves different governance models with regulatory agencies, air navigation service providers, local authorities, and UAV operators.

Socio-Economic Impacts: UAV deployment in smart cities is expected to have significant socio-economic impacts by providing cost-effective, on-demand, environmentally-friendly solutions for various applications. These impacts include economic growth, development of smart city infrastructure and services, enhanced connectivity, real-time information, flexibility, mobility, accessibility to remote areas, and reduced response time in emergencies.

Policy Implications: The study emphasizes the need for appropriate policies and regulations to ensure the safe integration of UAVs into the aviation system and smart cities. Policies proposed include segregated airspace with zones, rules for flying, appropriate maps issued by regulatory agencies, and licensing and training requirements for UAV operators.

Potential Benefits of CPS Integration: Integration of UAVs into smart cities brings benefits like shorter operations distance, extended connectivity, real-time information, flexibility, improved surveillance, better traffic and crowd management, enhanced disaster monitoring, environmental management, and support for commercial activities and urban air mobility.

Challenges Highlighted: The study highlights challenges in integrating UAVs into smart cities, including safety, privacy, security, airspace management, regulatory gaps, infrastructure needs, monitoring, emergency response, capacity limits, and the necessity for advanced technologies like detect and avoid systems. It stresses addressing human factors and fostering collaboration among stakeholders for successful UAV integration.

Challenges and Opportunities in Smart City Development

Smart city development presents both challenges and opportunities for policymakers, urban planners, and stakeholders. Challenges include the high costs of technology deployment, the complexity of integrating diverse systems and stakeholders, regulatory barriers, and the risk of exacerbating social inequalities. Additionally, concerns about data privacy, cybersecurity, and ethical implications must be carefully addressed to build public trust and ensure the responsible use of technology in urban environments.

At the same time, smart city initiatives offer opportunities to improve urban livability, promote environmental sustainability, foster economic growth, and enhance social inclusion. By leveraging technology and data-driven approaches, cities can optimize resource allocation, enhance service delivery, and empower citizens to participate in decision-making processes. Moreover, smart city development can stimulate innovation ecosystems, attract investment, and create new opportunities for job creation and economic development.

The literature review insights provide a foundation for the comparative analysis of smart city initiatives in Western societies and West African urban centers, which will be further explored in subsequent sections of the research study.

Methodology

Research Design

Given the complexity and interdisciplinary nature of smart cities and CPS, a scoping review was adopted, which enables an extensive examination of existing literature while identifying research gaps, regional disparities, challenges, and best practices in smart city development. Figure *2* gives a visual representation of the steps in achieving the objectives of this study using the scoping framework.

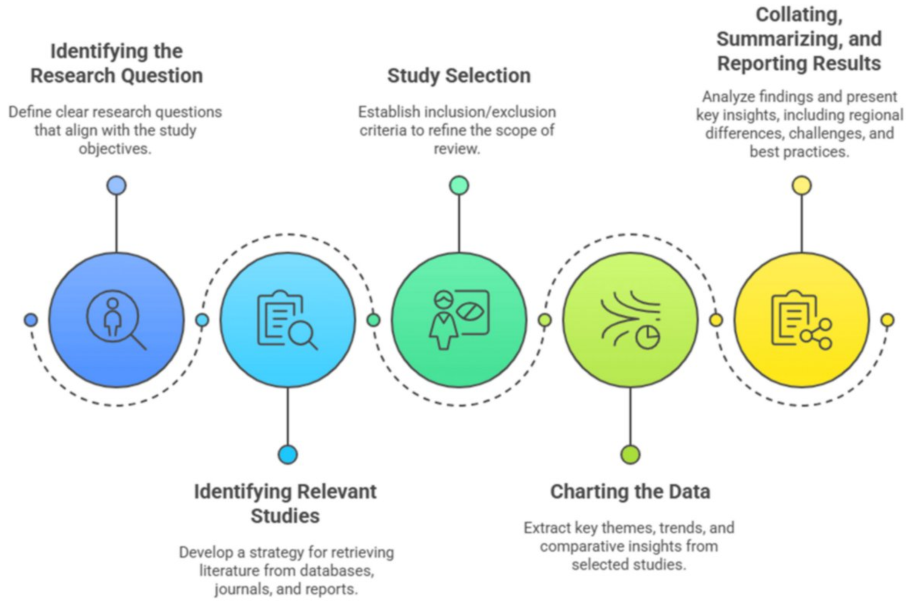

FIGURE 2: A Five-Step Methodological Approach

Literature Review Framework: Scoping Review Methodology

Rationale for adopting the scoping review framework: The rationale for a thorough and systematic analysis of CPS integration in Western urban centers and West African cities includes the need for a broad thematic exploration, which is needed to assess diverse smart city strategies and CPS applications. The policies and cultural differences call for a structured comparative analysis between Western and West African urbanization models, and also the need to determine which areas lack sufficient research. The study relied on the scooping review framework, and foundational sources for this review approach are based on Arksey and O'Malley study [36]. The thematic analysis from the scoping review will reveal key disparities in smart city infrastructure, governance policies, and CPS deployment strategies between Western and West African cities. These findings will highlight the need for tailored urbanization strategies that address region-specific constraints and opportunities.

Step-by-Step Implementation

1. Identifying the Research Questions

The following are the research questions for this study:

a) How do smart city initiatives in Western societies compare to those in West African urban centers in terms of development and deployment strategies?

b) In what ways are CPS technologies integrated within the urban infrastructure of Western and West African cities, and how do these approaches differ?

c) What are the key challenges, opportunities, and disparities that influence smart city development and CPS integration in Western societies and West African urban centers?

d) What lessons and best practices from existing smart city implementations can be adapted for global urban development, particularly in emerging regions?

2. Identifying Relevant Studies

The approach to searching included querying multiple scholarly repositories, specifically Google Scholar and Scopus, to identify relevant studies published in the last decade. The search keywords covered various combinations of "smart city," "smart cities," "intelligent cities," and "cyber-physical systems (CPS)," along with related technological themes such as "IoT" and "AI." The inclusion criteria focused on English-language publications that were final, peer-reviewed journal articles. For Scopus, the following search query was used, yielding a set of relevant documents: (TITLE-ABS-KEY("smart city" OR "smart cities")

AND TITLE-ABS-KEY("cyber-physical system" OR "CPS")) AND (AFFILCOUNTRY("United States" OR "Canada" OR "Australia" OR "New Zealand" OR "Nigeria" OR "Ghana" OR "Senegal" OR "Côte d'Ivoire" OR "Ivory Coast" OR "Benin" OR "Togo" OR "Mali" OR "Burkina Faso" OR "Europe")) AND (LIMIT-TO (LANGUAGE,"English")) AND (LIMIT-TO (PUBSTAGE,"final")) AND (LIMIT-TO (SRCTYPE,"j")) AND (LIMIT-TO (DOCTYPE,"ar")). For Google Scholar, the search was refined using the following keywords: ("smart cities" OR "intelligent cities") AND ("cyber-physical systems" OR "CPS") AND ("IoT" OR "AI") AND ("Europe" OR "United States" OR "Canada" OR "Australia" OR "New Zealand" OR "West Africa"), with additional filters applied: Year Filter "Since 2015," and filetype:pdf to locate full-text academic papers.

3. Study Selection Criteria

Inclusion criteria will focus on studies related to smart city development, CPS integration, and comparative urbanization research, particularly those examining case studies from Western societies and West African cities. Research articles, reports, and policy papers that provide empirical data, technological insights, or urban development frameworks will be prioritized. Conversely, studies that lack direct relevance, such as those solely addressing theoretical models without practical application, general urban planning without a focus on smart technologies, or discussions unrelated to urban innovation, will be excluded. This approach ensures a focused and meaningful synthesis of literature aligned with the study’s objectives.

4. Charting the Data

Key information will be systematically extracted to identify research themes, methodologies, case study locations, challenges, and success factors relevant to smart city development and CPS integration. Data extraction will focus on regulatory and self-regulatory approaches, as well as international harmonization versus experimental and adaptive governance. A comparative table will be used to present these governance models, providing insights into their strengths, limitations, and applicability in different urban contexts. Case studies from the West and West African cities will be analyzed to highlight diverse implementation strategies, policy frameworks, and technological adoption. This structured approach ensures a comprehensive understanding of how different regions navigate smart city innovations while addressing governance challenges and opportunities.

5. Collating, Summarizing, and Reporting Results

The findings will be synthesized using a thematic analysis approach, allowing for a structured comparison of smart city initiatives and CPS integration across different urban contexts. Key themes will include comparative perspectives such as the conceptual framework for CPS integration, implementation strategies in Western societies, including public-private partnerships, testbeds, and pilot projects, and data governance frameworks. The analysis will also highlight challenges and innovations in West African urban centers, assessing their impact on urban development and quality of life. Results will be presented using visual representations such as tables and charts, where applicable, to compare governance models, technological adoption, and policy effectiveness. Lessons learned, best practices, and implications for policy and practice will be outlined, leading to recommended strategies for future implementation. The study will suggest directions for further research, ensuring continuous improvement in smart city development and CPS integration.

Comparative analysis of smart cities in Western societies and West African urban centers

Overview of Smart City Initiatives

Smart city initiatives have gained momentum worldwide, aiming to leverage technology to improve urban living standards, enhance efficiency, and promote sustainability [25]. In Western societies, such as Europe and North America, smart city projects often focus on integrating advanced technologies, such as IoT sensors, data analytics, and AI algorithms, into urban infrastructure and services [37]. These initiatives aim to optimize transportation systems, energy usage, waste management, and public safety, among other aspects, to create more livable and resilient cities [25].

In contrast, smart city initiatives in West African urban centers are relatively nascent but rapidly emerging. These initiatives are driven by the need to address the challenges of rapid urbanization, including inadequate infrastructure, traffic congestion, and environmental pollution [29]. While West African smart city projects share similar goals with their Western counterparts, they often face additional hurdles related to limited resources, institutional capacity, and technological readiness [29].

Infrastructure and Technology Integration

Infrastructure and technology integration are central to the development of smart cities in both Western societies and West African urban centers. In Western cities, there is a significant emphasis on deploying cutting-edge technologies to create connected and intelligent urban environments [25]. This includes the integration of IoT devices, sensors, and communication networks into transportation systems, energy grids, buildings, and public services.

In West African urban centers, infrastructure challenges such as limited access to reliable electricity and internet connectivity pose barriers to technology integration. However, innovative solutions tailored to the local context, such as mobile applications for transportation management or solar-powered IoT sensors for environmental monitoring, are being explored to overcome these challenges and enhance urban services [6].

Governance and Policy Frameworks

Governance and policy frameworks play a crucial role in shaping smart city development strategies and implementation approaches. In Western societies, smart city initiatives are often supported by comprehensive governance structures and policy frameworks that promote collaboration between government agencies, private sector stakeholders, academia, and civil society [38]. This collaborative approach facilitates the co-creation of innovative solutions and the alignment of interests across different sectors.

In West African urban centers, governance and policy frameworks for smart city development are still evolving and may face challenges related to institutional capacity, regulatory frameworks, and political stability [27]. However, there is growing recognition of the importance of multi-stakeholder engagement, participatory decision-making, and inclusive governance models in driving sustainable urban development.

We can also carry out a Comparative Assessment of Policy and Governance Models that many Western societies have implemented to identify governance gaps and barriers, informing potential policy reforms and capacity-building efforts for effective implementation of CPS-enabled solutions. In Tables *1* and 2, the different approaches are compared, using characteristics like description, advantages, and challenges [39].

Characteristics	Regulatory Approach	Self-Regulatory Approach
Description	This model involves the establishment of regulations and standards by governmental bodies to govern the development, deployment, and operation of CPS. It may include laws, directives, and guidelines aimed at ensuring the safety, security, privacy, and ethical use of CPS.	Under this model, industry associations, consortia, or standards organizations develop voluntary standards and best practices for CPS governance. Companies voluntarily adhere to these standards to demonstrate their commitment to responsible conduct.
Advantages	Provides a clear legal framework for stakeholders to adhere to. Can enforce compliance with minimum safety and security standards.	Encourages industry self-governance and innovation. Allows for flexibility and adaptability to rapidly changing technologies.
Challenges	May lag behind technological advancements, leading to outdated regulations. Striking a balance between innovation and regulation can be challenging.	Different companies may adopt varying standards, leading to inconsistency. Compliance is voluntary and may not be universally adopted or enforced.

TABLE 1: Regulatory Approach vs Self-Regulatory Approach

Source: [39]

CPS: Cyber Physical Systems

Characteristics	International Harmonization	Experimental and Adaptive Governance
Description	In this model, efforts are made to harmonize policies and standards across multiple jurisdictions to promote interoperability and facilitate global trade. International organizations and treaties may play a role in setting common standards.	This model emphasizes experimentation, learning, and adaptation in governance approaches for CPS. It involves iterative policymaking, stakeholder engagement, and feedback mechanisms to address emerging challenges and uncertainties.
Advantages	Reduces trade barriers and promotes global innovation. Ensures consistency in regulatory requirements for multinational corporations.	Flexibility to respond to rapidly evolving technologies and risks. Encourages innovation and experimentation in governance mechanisms.
Challenges	Sovereignty issues: Countries may prioritize national interests over international harmonization efforts. Complexity: Harmonizing diverse regulatory frameworks across different legal systems and cultures can be complex.	Uncertainty: Experimentation may lead to unintended consequences or regulatory gaps. Accountability: Balancing experimentation with accountability and risk management is essential.

TABLE 2: International Harmonization vs Experimental and Adaptive Governance

Source: [39]

CPS: Cyber Physical Systems

Socio-Economic Factors Impacting Smart City Development

Socio-economic factors play a significant role in shaping smart city development trajectories in both Western societies and West African urban centers. In Western cities, factors such as income levels, education, digital literacy, and social inclusion influence the adoption and acceptance of smart city technologies [25]. Moreover, disparities in access to resources and services may exacerbate socio-economic inequalities within urban populations.

In West African urban centers, socio-economic factors such as poverty, informal employment, and inadequate social infrastructure pose challenges to smart city development [29]. However, initiatives that prioritize inclusivity, affordability, and accessibility have the potential to address these disparities and improve the quality of life for all residents.

Case Studies: Examples From Western Cities and West African Urban Centers

To illustrate the comparative analysis, case studies from selected Western cities and West African urban centers are examined. These case studies provide insights into specific smart city projects, their objectives, implementation strategies, and outcomes. By comparing and contrasting these examples, the study aims to identify best practices, lessons learned, and opportunities for knowledge exchange and collaboration between Western and West African smart city initiatives.

Case Study: Urban Agriculture Integration in Accra, Ghana [40].

Objective: To explore the integration of urban agriculture in Accra to enhance food security and promote sustainable urban development.

Implementation Strategies: Conduct a feasibility study on urban agriculture potential, engage local communities in agricultural initiatives, and establish urban farming zones.

Outcomes: Increased food production, improved access to fresh produce, enhanced community engagement, and sustainable urban food systems in Accra.

Case Study: Digital Governance in Bamako, Mali [41].

Objective: To implement digital governance initiatives in Bamako to enhance citizen engagement, improve service delivery, and promote transparent governance.

Implementation Strategies: Develop digital platforms for citizen participation, establish e-governance systems, and enhance data transparency.

Outcomes: Increased citizen engagement, improved service delivery efficiency, enhanced transparency, and accountable governance in Bamako.

Case Study: Smart Cities Initiatives in Lagos, Nigeria [42].

Objectives: The Lagos Smart City initiative aims to Connect human capital, social capital, and ICT infrastructure to address public issues, achieve sustainable development within Lagos, and enhance the quality of life for citizens through technological advancements and smart solutions.

Implementation Strategies: Implement components such as e-government, safe city measures, mobility/WiFi/digital citizens, open data, smart farming/agriculture, smart buildings, and smart grid/energy/utilities.

Outcomes: Enhanced security measures to create a safer environment for residents. Improved transportation systems to ease mobility and reduce congestion. Upgraded infrastructure to support the city's growth and development. Increased connectivity through the implementation of advanced technologies.

Case Study: Smart Mobility Solutions in Barcelona, Spain [43].

Objective: To enhance urban mobility and reduce traffic congestion through smart transportation solutions.

Implementation Strategies: Implement bike-sharing programs, develop pedestrian-friendly infrastructure, and introduce smart traffic management systems.

Outcomes: Improved transportation efficiency, reduced carbon emissions, increased cycling rates, and enhanced urban livability.

Case Study: Sustainable Energy Initiatives in Copenhagen, Denmark [44].

Objective: To promote renewable energy integration and reduce carbon footprint in the city.

Implementation Strategies: Invest in wind energy projects, implement district heating systems, and incentivize energy-efficient buildings.

Outcomes: Reduced reliance on fossil fuels, lower greenhouse gas emissions, increased energy efficiency, and sustainable energy practices.

CPS integration in smart cities: Comparative perspectives

Conceptual Framework for CPS Integration

The conceptual framework for CPS integration in smart cities provides a theoretical basis for understanding the interplay between physical infrastructure, digital technologies, and urban processes [33]. It encompasses connectivity, interoperability, data analytics, and automation principles to enable seamless interaction between physical and digital components within urban environments. Key elements of the framework are as follows:

1. Interconnectivity: CPS integration involves connecting diverse systems and devices to enable data exchange and communication.

2. Interoperability: Ensuring compatibility and seamless interaction between different CPS components and systems.

3. Data Analytics: Leveraging data collected from sensors and devices to derive insights and inform decision-making processes.

4. Automation: Utilizing AI algorithms and machine learning techniques to automate processes and optimize system performance.

Implementation Strategies in Western Societies

In Western societies, CPS integration in smart cities is guided by comprehensive strategies and roadmaps that prioritize innovation, sustainability, and citizen-centric approaches [40]. Implementation strategies typically are as follows:

1. Public-Private Partnerships: Collaboration between government, industry, academia, and civil society to

develop and deploy CPS solutions.

2. Testbeds and Pilot Projects: Establishing testbeds and pilot projects to evaluate CPS technologies in real-world urban environments.

3. Data Governance Frameworks: Establishing data governance frameworks to ensure responsible and ethical use of data collected from CPS systems.

4. Regulatory Support: Implementing supportive regulatory frameworks to encourage innovation while addressing privacy, security, and interoperability concerns.

5. Capacity Building: Investing in workforce development and skills training to build expertise in CPS technologies and implementation.

Challenges and Innovations in West African Urban Centers

In West African urban centers, CPS integration faces unique challenges related to infrastructure constraints, limited resources, and institutional capacity [6]. However, innovative approaches and localized solutions are emerging to address these challenges, including:

1. Adaptation of Technology: Customizing CPS technologies to suit the local context and overcome infrastructure limitations, such as using mobile-based solutions for data collection and communication.

2. Community Engagement: Engaging local communities in the design and implementation of CPS initiatives to ensure relevance, acceptance, and sustainability.

3. Partnership Models: Leveraging partnerships between the government, private sector, and international organizations to access funding, expertise, and technical support.

4. Leapfrogging Opportunities: Capitalizing on leapfrogging opportunities by bypassing traditional infrastructure development and embracing cutting-edge technologies for rapid urban transformation.

Impact on Urban Development and Quality of Life

CPS integration in smart cities has significant implications for urban development and quality of life in both Western societies and West African urban centers [14]. Key impacts are as follows:

1. Efficiency and Optimization: Improving the efficiency of urban services and infrastructure through real-time monitoring, predictive analytics, and automated control systems.

2. Sustainability: Promoting environmental sustainability by reducing resource consumption, minimizing emissions, and enhancing energy efficiency.

3. Resilience and Adaptation: Enhancing urban resilience to natural disasters, climate change, and other shocks through early warning systems and adaptive infrastructure.

4. Inclusive Growth: Fostering inclusive growth by expanding access to essential services, promoting economic opportunities, and addressing socio-economic disparities.

Lessons Learned and Best Practices

Through comparative analysis, several lessons learned and best practices emerge from CPS integration in smart cities:

1. Collaboration and Partnership: Collaboration between diverse stakeholders is essential for successful CPS integration.

2. Contextualization: Solutions must be tailored to the local context to ensure relevance and effectiveness.

3. Capacity Building: Investment in capacity building and skills development is critical for sustainable CPS implementation.

4. Innovation and Flexibility: Embracing innovation and flexibility is key to overcoming challenges and seizing opportunities in CPS integration.

5. Continuous Evaluation: Regular evaluation and monitoring are necessary to assess the impact of CPS initiatives and identify areas for improvement.

Discussion

Key Findings From Comparative Analysis

The comparative analysis between Western and West African urbanization regarding smart cities and CPS integration has yielded several key findings:

1. Development Disparities: Western cities exhibit advanced levels of smart city development and CPS integration compared to West African urban centers, which face infrastructure constraints and limited resources.

2. Technological Divide: While Western cities deploy sophisticated CPS technologies across various sectors, West African urban centers focus primarily on basic service delivery and face challenges related to technology access and adoption.

3. Governance and Policy: Western societies have established robust governance frameworks and policies supporting smart city initiatives, while West African countries are in the early stages of developing such frameworks, with a growing emphasis on participatory approaches.

4. Socio-Economic Impacts: CPS integration in Western cities has led to significant improvements in urban efficiency, sustainability, and quality of life, while in West African urban centers, incremental progress has been observed, with potential for transformative impact in the long term.

5. Community Engagement: Public awareness and engagement in smart city initiatives are high in Western societies, contributing to the success of CPS integration, whereas in West African urban centers, efforts to engage communities are gaining momentum but require further emphasis.

Implications for Policy and Practice

The findings of this comparative study have several implications for policy-making and practice:

1. Policy Alignment: Policymakers in West African countries should prioritize the development of supportive governance frameworks and policies to facilitate CPS integration and smart city development, drawing lessons from Western experiences while considering local contexts.

2. Capacity Building: Investments in capacity building and skills development are essential to enhance technological literacy and empower local communities to participate in smart city initiatives effectively.

3. Resource Allocation: Governments and international organizations should allocate adequate resources and funding support to facilitate CPS integration in West African urban centers, ensuring equitable access to technology and promoting inclusive development.

4. Partnerships and Collaboration: Collaboration between government, private sector, academia, and civil society is critical to driving CPS integration and smart city development, fostering innovation, and leveraging resources and expertise across sectors.

Recommended Strategies

To address disparities and promote inclusive smart city development, the following strategies are recommended:

1. Localized Solutions: Tailoring CPS technologies and smart city initiatives to the specific needs and challenges of West African urban centers, considering factors such as infrastructure constraints, resource limitations, and socio-economic disparities.

2. Community-Centric Approaches: Adopting community-centric approaches that prioritize the needs and preferences of local residents, engage communities in decision-making processes, and promote inclusive participation in smart city development.

3. Capacity Development: Investing in capacity development programs to build technical expertise, foster innovation ecosystems, and empower local stakeholders to drive CPS integration and smart city initiatives.

4. Knowledge Exchange: Facilitating knowledge exchange and collaboration between Western and West African cities, leveraging best practices, lessons learned, and expertise to accelerate smart city development and CPS integration in the region.

Future Directions for Research and Implementation

Future research and implementation efforts should focus on:

1. Longitudinal Studies: Conduct longitudinal studies to monitor the progress and impact of CPS integration and smart city initiatives in both Western and West African contexts, tracking trends, identifying emerging challenges, and evaluating the effectiveness of policy interventions and technological innovations over time.

2. Policy Evaluation: Evaluating the effectiveness of governance frameworks, policies, and regulatory measures in facilitating CPS integration and smart city development, identifying gaps and areas for improvement, and informing evidence-based policy-making.

3. Technology Innovation: Promoting innovation in CPS technologies tailored to the needs and constraints of West African urban centers, including the development of low-cost, scalable solutions, and alternative energy sources to overcome infrastructure challenges and resource limitations.

4. Inclusive Development: Prioritizing inclusive development approaches that ensure equitable access to smart city services and benefits for all residents, particularly vulnerable and marginalized populations, and addressing socio-economic disparities through targeted interventions and community empowerment initiatives.

By addressing these research directions and implementing the recommended strategies, policymakers, urban planners, and stakeholders can advance the agenda of inclusive smart city development and CPS integration, fostering sustainable, resilient, and equitable urbanization in both Western societies and West African urban centers.

Summary of findings

This comparative study between Western and West African urbanization regarding smart cities and CPS integration has revealed significant disparities in the development, deployment, and impact of smart city initiatives. Western cities exhibit advanced levels of smart city development, extensive deployment of CPS technologies, and robust governance frameworks supporting innovation and sustainability. In contrast, West African urban centers face infrastructure constraints, limited resources, and nascent governance structures, resulting in incremental progress in CPS integration and smart city development.

Contributions to Knowledge

This research study contributes to the existing body of knowledge by providing insights into the challenges, opportunities, and implications of smart city development and CPS integration in diverse geographical and socio-economic contexts. By conducting a comparative analysis between Western societies and West African urban centers, the study sheds light on the disparities in technology adoption, governance frameworks, and socio-economic impacts, highlighting the need for context-specific approaches and inclusive strategies in smart city development.

Recommendations for Future Action

Based on the findings of this study, several recommendations for future action are proposed:

1. Policy Alignment: Policymakers in West African countries should prioritize the development of supportive governance frameworks and policies to facilitate CPS integration and smart city development, drawing lessons from Western experiences while considering local contexts.

2. Capacity Building: Investments in capacity building and skills development are essential to enhance technological literacy and empower local communities to effectively participate in smart city initiatives.

3. Resource Allocation: Governments and international organizations should allocate adequate resources and funding support to facilitate CPS integration in West African urban centers, ensuring equitable access to technology and promoting inclusive development.

4. Partnerships and Collaboration: Collaboration between government, private sector, academia, and civil society is critical to driving CPS integration and smart city development, fostering innovation, and

leveraging resources and expertise across sectors.

5. Address data privacy concerns and cybersecurity risks in smart city implementations.

Conclusions

In conclusion, while the journey towards smart cities and CPS integration may differ between Western societies and West African urban centers, the overarching goal of leveraging technology to improve urban livability, enhance efficiency, and promote sustainability remains the same. By addressing disparities, fostering collaboration, and prioritizing inclusive development approaches, policymakers, urban planners, and stakeholders can work towards realizing the vision of smart, resilient, and equitable cities for all.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Obumneme Ukandu, Afolashade Kuyoro, Samuel Okolie

Acquisition, analysis, or interpretation of data: Obumneme Ukandu, Afolashade Kuyoro, Folasade Ayankoya, Samuel Okolie

Drafting of the manuscript: Obumneme Ukandu, Afolashade Kuyoro, Folasade Ayankoya, Samuel Okolie

Critical review of the manuscript for important intellectual content: Obumneme Ukandu, Afolashade Kuyoro, Folasade Ayankoya, Samuel Okolie

Supervision: Afolashade Kuyoro, Folasade Ayankoya, Samuel Okolie

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