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SOCIO-TECHNICAL SYSTEMS FOR SMART CITIES: BRIDGING TECHNOLOGY AND SOCIETY. CASE STUDY: ROMANIA'S URBAN LANDSCAPE AND DIGITAL INFRASTRUCTURE

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ABSTRACT: Smart cities represent one of the most ambitious urban development initiatives of the 21st century, promising to leverage digital technology to enhance efficiency, sustainability, and quality of life. However, the success of these initiatives depends not merely on technological sophistication but on the complex interplay between technological systems and the social, institutional, and human dimensions they serve. This is where socio-technical systems thinking becomes essential. A socio-technical system is an integrated perspective that recognizes how technology and society co-evolve, shaping each other in a continuous feedback loop. In the context of smart cities, this approach acknowledges that technological infrastructure, human behavior, organizational structures, policies, and cultural values must all work together harmoniously for urban innovations to achieve their intended impact.

KEYWORDS: smart cities, socio-technical systems, digital infrastructure, Romania, urban-rural disparities, digital inclusion

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1. INTRODUCTION

Smart cities represent one of the most ambitious urban development initiatives of the 21st century, promising to leverage digital technology to enhance efficiency, sustainability, and quality of life. However, the success of these initiatives depends not merely on technological sophistication but on the complex interplay between technological systems and the social, institutional, and human dimensions they serve.

Socio-technical systems theory emerged from organizational studies and has become increasingly relevant to urban planning and technology governance. The fundamental principles include:

Mutual Shaping: Technology does not simply impose changes on society; rather, social actors shape technology through design choices, adoption patterns, and contestation.

Heterogeneous Elements: Socio-technical systems comprise diverse elements-technical artifacts, people, institutions, policies, natural environments, and knowledge-that are interdependent.

Dynamic Evolution: These systems continuously evolve through learning, adaptation, and sometimes rupture, as new actors, technologies, or social demands emerge.

Multiple Stakeholders: Smart cities involve numerous stakeholders-municipal governments, private technology companies, residents, civil society organizations, and infrastructure operators-each with different interests.

2. UNDERSTANDING SOCIO-TECHNICAL SYSTEMS

Socio-technical systems theory emerged from organizational studies and has become increasingly relevant to urban planning and technology governance. Technology and society co-evolve through mutual shaping, heterogeneous elements, dynamic evolution, and multiple stakeholder interactions.

3. ROMANIA'S URBAN LANDSCAPE

Romania's Urban Landscape: Major Cities and Population Distribution

Romania exhibits a polycentric urban system characterized by the overwhelming demographic, economic, and administrative dominance of Bucharest, complemented by a network of regional growth poles that perform important economic, educational, cultural, and logistical functions. This urban hierarchy has been shaped by historical development, industrialization during the communist period, post-1990 economic restructuring, and Romania's integration into the European Union. Understanding this spatial distribution is essential for analyzing the country's potential for smart city development, as urban size, economic specialization, governance capacity, and regional connectivity significantly influence the adoption and effectiveness of digital technologies.

Bucharest remains Romania's undisputed metropolitan center, with approximately 2.14 million inhabitants in 2023. As both the political capital and the country's primary economic engine, it generates a disproportionately large share of national GDP, concentrates the headquarters of major public institutions and multinational companies, and hosts Romania's largest universities and research centers. This concentration of population, financial resources, and institutional capacity enables Bucharest to implement sophisticated digital infrastructure and smart city initiatives more rapidly than other municipalities. At the same time, however, this urban primacy creates territorial imbalances, as investment, innovation, and highly skilled labor tend to concentrate in the capital at the expense of smaller cities and peripheral regions.

Romania's second tier of cities serves as regional development hubs with distinct economic profiles. Iași has emerged as the principal educational and technological center of northeastern Romania, benefiting from a strong university ecosystem and an expanding information technology sector. Cluj-Napoca has established itself as one of Central and Eastern Europe's leading innovation ecosystems, driven by a dynamic ICT industry, entrepreneurial culture, and significant foreign investment. Timișoara functions as a major industrial, manufacturing, and logistics center due to its strategic position near Romania's western border and its strong integration into European production networks. Constanța, located on the Black Sea coast, combines maritime transport, tourism, and energy-related activities through the Port of Constanța, one of Europe's largest maritime gateways. Craiova, Brașov, and Galați similarly perform important regional functions through their industrial heritage, manufacturing sectors, transport infrastructure, and educational institutions.

The following table shows Romania's major urban centers:

City	Region	Population (2023)
Bucharest	Capital/Wallachia	2,140,000
Iași	Moldavia/Northeast	392,600
Cluj-Napoca	Transylvania	332,200
Timișoara	Western/Banat	340,000
Constanța	Black Sea/Southeast	337,800
Craiova	Wallachia/South	317,600
Brașov	Transylvania	309,600
Galați	Danube/Southeast	342,400

Source: Statista (2023), World Population Review.
Note: Bucharest's concentration of over 11% of Romania's total population demonstrates the urban primacy characteristic common in Central/Eastern European capitals.

Digital Infrastructure in Romanian Cities (2023-2024)

Romania has made significant investments in digital infrastructure, particularly in broadband connectivity. This table reflects the state of internet access and digital infrastructure across urban areas:

Infrastructure Indicator	Urban Areas	Rural Areas
Household Internet Access	95%+	90-93%
Fixed Broadband ≥100 Mbps	94%	65.4%
Average Fixed Broadband Speed	587 Mbps	~400 Mbps
Mobile Broadband (4G/5G Users)	~90%	~80%
Average Broadband Cost (Monthly)	€7.50-8.00	€7.50-8.00
Municipalities with 100+ Mbps Coverage	1,964 of 3,001	65.4%

Source: Eurostat, ANCOM (National Authority for Administration and Regulation in Communications), 2023-2024. Note: Romania ranks 3rd in EU for average broadband speed and has some of the most affordable internet services in Europe.

Although Romania possesses several economically dynamic regional cities, the country's urban system remains considerably more centralized than those of many Western European states. Bucharest alone accounts for more than 11% of Romania's total population and an even larger proportion of national economic output, investment, and high-value services. Such concentration is characteristic of many Central and Eastern European countries, where capital cities frequently dominate national development patterns. While this concentration facilitates economies of scale and supports advanced digital innovation within metropolitan areas, it may also contribute to regional disparities in infrastructure quality, public services, employment opportunities, and technological investment.

From a socio-technical perspective, these demographic and territorial characteristics have important implications for smart city development. Large metropolitan areas generally possess greater financial resources, stronger institutional capacity, more mature digital ecosystems, and higher levels of human capital, enabling them to adopt complex smart city technologies more rapidly. Conversely, medium-sized cities and smaller municipalities often face budgetary limitations, shortages of specialized personnel, fragmented administrative structures, and lower levels of digital maturity. Consequently, implementing identical smart city models across all Romanian municipalities would likely produce uneven outcomes and reinforce existing territorial inequalities.

These differences suggest that Romania should pursue a differentiated approach to smart city policy. While Bucharest and major regional centres may focus on advanced applications such as artificial intelligence, digital twins, intelligent transport systems, and integrated urban data platforms, smaller municipalities may benefit more from investments in digital public services, broadband expansion, administrative digitalization, energy efficiency, and citizen engagement platforms. Such an approach reflects the core principles of socio-technical systems thinking, which emphasize adapting technological solutions to local institutional capacities, demographic characteristics, and community needs rather than replicating standardized technological models.

Ultimately, Romania's urban landscape presents both significant opportunities and important challenges for digital transformation. The country's network of regional growth poles provides multiple centers capable of driving innovation beyond the capital, while the continued dominance of Bucharest highlights the necessity of balanced territorial development. Ensuring that smart city initiatives contribute to national cohesion will require coordinated investment, knowledge sharing among municipalities, and governance frameworks that enable technological innovation to benefit cities of different sizes and levels of socio-economic development.

Digital Skills and Internet Usage in Romania (Urban vs. Rural) - 2023

A critical aspect of socio-technical systems is human capacity and digital skills. This table illustrates the digital divide in Romania across different activities and urban-rural dimensions:

Digital Activity	Urban (Cities)	Rural Areas
Daily Internet Users (16-74)	81.6%+	~60-70%
Email/Communication Online	~80%	~33%
Reading Online News	~75%+	<50%
Online Banking	~50-60%	<15%
E-commerce (Buying/Ordering Online)	~60%+	~40-50%
Basic Digital Skills (Using Computers)	~70%+	~45-50%

Source: Eurostat (2023), Digital Society Statistics. Note: Romania still shows significant urban-rural disparities in digital skills and internet usage, reflecting broader challenges in digital inclusion and e-participation, critical for smart city implementations.

Socio-Economic Context: Urban-Rural Disparities in Romania (2023)

Understanding the socio-economic context is essential for implementing socio-technical systems in smart cities. Romania exhibits significant disparities between urban and rural areas:

Socio-Economic Indicator	Urban Areas	Rural Areas
Risk of Poverty/Social Exclusion	18.5%	45.1%
Median Equivalised Net Income (PPS)	€14,497	€8,579
Bucharest Metropolitan GDP as % of National GDP	~13%	-
Bucharest Metropolitan GDP per Inhabitant (Relative to National Avg)	2.1x National Avg	-

Source: Eurostat (2023), Urban-Rural Europe Statistics; National Bank of Romania. Note: Romania demonstrates one of the largest urban-rural disparities in the EU, with rural poverty rates 26.6 percentage points higher than urban areas and rural median incomes less than 60% of urban levels.

4. IMPLICATIONS FOR SMART CITIES IN ROMANIA

The data presented above reveals important socio-technical considerations for smart city development in Romania:

1. Digital Infrastructure as a Prerequisite, Not a Solution: While Romania has made impressive strides in broadband infrastructure-ranking among the best in the EU for speed and affordability—this technological achievement has not automatically translated into high digital skills adoption or reduced urban-rural disparities. This exemplifies the socio-technical principle that technology deployment requires parallel investment in human capacity, institutional frameworks, and social engagement.

2. The Urban Primacy Challenge: Bucharest's economic concentration (generating twice the national GDP average per capita while housing only ~11% of the population) reflects classic urban primacy issues. Smart city initiatives risk exacerbating this if they concentrate investment in capital cities. Successful socio-technical approaches must ensure benefits reach secondary cities (Cluj-Napoca, Timișoara, Iași) and smaller municipalities.

3. The Digital Skills Divide: Despite excellent broadband access, significant gaps persist in digital skills adoption-rural residents use online banking at rates below 15% compared to 50-60% in cities. This suggests that socio-technical systems implementation must include robust digital literacy programs addressing the social and institutional dimensions alongside technological deployment.

4. Equity as a Design Principle: With rural poverty rates 26.6 percentage points higher than urban areas, smart city initiatives must actively address equity. Technologies must not reproduce existing inequalities but instead be designed to address the specific needs and challenges of marginalized communities.

Smart Cities: A Socio-Technical Perspective Beyond Technology-Centric Approaches

Conventional smart city narratives often focus excessively on technological capabilities: artificial intelligence, Internet of Things (IoT) sensors, data analytics, and automation. While these technologies are essential tools, they represent only one dimension of a successful smart city. A socio-technical perspective reveals that technology is not neutral, social adoption is critical, institutional capacity matters, and context is everything.

Implementation Challenges: A Socio-Technical Lens

The Integration Challenge

Most smart city initiatives begin with specific technological solutions-traffic management systems, smart grids, or sensor networks-deployed in isolation. Socio-technical systems thinking reveals that fragmented approaches underutilize technology's potential and create maintenance problems.

The Equity and Inclusion Problem

Smart city technologies risk creating digital divides. Romania's data illustrates this clearly: wealthier urban neighborhoods receive more investment in smart infrastructure, while marginalized rural communities experience lower digital adoption despite infrastructure availability.

Operationalizing Socio-Technical Systems Thinking

Translating socio-technical systems theory into practical smart city policies requires moving beyond isolated technological deployments toward integrated governance frameworks that recognize the interdependence of technology, institutions, and society. For Romania, this transition is particularly important because the country simultaneously benefits from advanced digital infrastructure while

continuing to face significant regional inequalities, institutional capacity constraints, and uneven digital literacy. Consequently, the effectiveness of smart city initiatives depends not only on technological innovation but also on the ability of public institutions, private organizations, and citizens to collaboratively shape digital transformation.

Participatory Design and Citizen Engagement

A socio-technical approach emphasizes that citizens should not merely be users of smart city technologies but active participants in their design, implementation, and evaluation. Municipal governments should establish participatory mechanisms such as public consultations, digital engagement platforms, citizen assemblies, and co-creation workshops to ensure that technological solutions address genuine local needs. This is particularly relevant for Romania's secondary cities and rural municipalities, where local priorities often differ significantly from those of Bucharest or other major metropolitan areas. By involving residents throughout the planning process, municipalities can increase public trust, improve technology adoption, and reduce resistance to digital transformation while strengthening democratic governance.

Integrated Infrastructure Planning

Rather than introducing isolated technological projects, smart city development should be based on integrated urban planning that connects transportation, energy, healthcare, education, environmental monitoring, public safety, and administrative services into a coherent digital ecosystem. Socio-technical systems thinking encourages policymakers to begin with societal challenges-such as traffic congestion, pollution, energy efficiency, demographic decline, or access to public services-and subsequently identify technologies capable of addressing these interconnected problems. Such an approach avoids fragmented investments, promotes interoperability between municipal information systems, and ensures that technological innovation contributes directly to broader sustainability and quality-of-life objectives.

Capability Building and Institutional Capacity

Technology alone cannot transform cities without institutions capable of managing increasingly complex digital infrastructures. Romanian municipalities vary considerably in their administrative resources, technical expertise, and financial capacity. Consequently, investment in human capital is equally important as investment in digital infrastructure. National and local governments should expand continuous professional training for municipal employees in digital governance, cyber-security, data management, artificial intelligence, and evidence-based policy making. Simultaneously, broader digital literacy initiatives targeting citizens-including elderly populations, disadvantaged groups, and rural communities-can strengthen digital participation and ensure that public services become accessible to all segments of society.

Equity-Focused Implementation

Socio-technical systems theory argues that technological innovation should reduce rather than reinforce existing social inequalities. Romania's pronounced urban-rural disparities in income, digital skills, and access to public services make equity a central design principle for smart city policies. Public investment should therefore prioritize inclusive digital infrastructure, accessible e-government services, affordable broadband connectivity, and digital education programs in underserved communities.

Multi-Level Governance and Cross-Sector Collaboration

Smart city implementation extends beyond the responsibilities of municipal governments. Successful socio-technical transformation requires coordination among national ministries, regional authorities, universities, technology companies, utilities, civil society organizations, and local communities. Romania's smart city initiatives would benefit from stronger public-private partnerships, collaborative research projects, and knowledge-sharing networks among municipalities. Universities can contribute scientific expertise and innovation, while private-sector partners provide technological capabilities and investment. National government, meanwhile, plays a critical coordinating role by establishing interoperability standards, funding mechanisms, and strategic policy frameworks aligned with the European Digital Decade objectives.

Continuous Monitoring, Evaluation, and Adaptive Governance

Socio-technical systems are inherently dynamic, requiring continuous learning and adaptation rather than fixed implementation plans. Romanian smart city initiatives should therefore establish comprehensive monitoring systems that evaluate not only technological performance but also social outcomes, institutional effectiveness, citizen satisfaction, environmental sustainability, and

economic impact. Performance indicators should combine quantitative metrics-such as energy savings, traffic efficiency, broadband usage, and service accessibility-with qualitative assessments of citizen trust, social inclusion, and community well-being. Lessons learned from pilot projects should inform future policy adjustments, creating adaptive governance processes capable of responding to evolving technological opportunities and societal expectations.

Ultimately, operationalizing socio-technical systems thinking requires recognizing that smart cities are not simply collections of advanced technologies but complex socio-technical ecosystems where technological innovation, institutional capacity, governance quality, and citizen participation evolve together. For Romania, leveraging its strong digital infrastructure while simultaneously addressing disparities in digital skills, administrative capacity, and regional development will determine whether smart city initiatives generate sustainable, inclusive, and resilient urban transformation. This integrated perspective positions technology not as an end in itself, but as an enabling instrument for improving social well-being, strengthening democratic governance, and enhancing the long-term sustainability of Romanian cities.

5. CONCLUSIONS

Smart cities represent a significant opportunity to improve urban quality of life through the strategic integration of digital technologies, sustainable urban planning, and citizen-centered governance. However, as demonstrated throughout this study, the success of smart city initiatives depends not simply on the deployment of advanced technologies but on the effective interaction between technological innovation, institutional capacity, and the social contexts in which these technologies operate. The socio-technical systems perspective provides a valuable analytical framework for understanding this complexity, emphasizing that technological solutions and social systems continuously shape one another through processes of adaptation, learning, and collaboration.

The Romanian experience highlights several important lessons for policymakers and urban planners. First, smart city strategies should be designed around clearly identified societal challenges rather than around technology itself. Digital technologies should function as enabling tools that improve mobility, environmental sustainability, public health, education, administrative efficiency, and citizen well-being instead of becoming objectives in their own right. Second, successful implementation requires strong institutional capacity, including digitally skilled public administrations capable of managing complex data ecosystems, ensuring cyber-security, and coordinating cross-sector collaboration. Third, citizens must be regarded as active participants in the design, implementation, and evaluation of smart city initiatives. Participatory governance increases transparency, strengthens public trust, and enhances the long-term acceptance and effectiveness of technological innovation.

Furthermore, equity must remain a central principle throughout the entire smart city development process. Romania's pronounced urban-rural disparities illustrate the risks associated with technology-driven development that primarily benefits economically stronger metropolitan regions. Future investments should therefore prioritize digital inclusion, equitable access to public services, and targeted support for smaller municipalities and disadvantaged communities. In this respect, socio-technical systems thinking offers an important normative perspective by placing social cohesion, accessibility, and public value alongside technological efficiency.

From a governance perspective, smart cities should be understood as dynamic and adaptive systems rather than fixed technological projects. Their success depends on continuous monitoring, policy learning, stakeholder collaboration, and the ability to adapt to changing technological capabilities and evolving societal expectations. National governments, local authorities, universities, private-sector organizations, and civil society all have complementary roles in creating resilient digital ecosystems capable of supporting sustainable urban development.

The findings presented in this article also contribute to the broader academic discussion on socio-technical transitions by demonstrating how technological innovation is mediated by institutional, economic, and cultural factors. Romania illustrates that countries with advanced digital infrastructure may still encounter substantial implementation challenges if investments in human capital, governance capacity, and social inclusion do not progress at a similar pace.

Future research could build upon this work by conducting comparative analyses between Romanian municipalities and other European smart cities, examining longitudinal developments in digital governance, or investigating the impact of

emerging technologies such as artificial intelligence, digital twins, and predictive urban analytics on socio-technical transformation. Such studies would contribute to a deeper understanding of how smart city ecosystems evolve over time and how governance models can adapt to rapidly changing technological landscapes.

Ultimately, the cities that will succeed in the coming decades will not necessarily be those equipped with the greatest number of sensors, platforms, or automated systems. Rather, they will be those capable of integrating technological capability with institutional resilience, democratic governance, ethical data management, and active citizen participation. The future of smart cities therefore lies in balancing technological innovation with human values, digital transformation with social inclusion, and operational efficiency with long-term sustainability. Romania's ongoing digital transformation demonstrates that achieving this balance is both the principal challenge and the greatest opportunity for creating resilient, inclusive, and genuinely intelligent urban environments.

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