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SUSTAINABLE URBAN INFRASTRUCTURE AND URBAN RESILIENCE IN ABUJA, NIGERIA: AN EMPIRICAL INVESTIGATION

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ABSTRACT

Rapid urbanisation and growing environmental and infrastructure pressures have increased the need for cities to develop sustainable, adaptable, and resilient infrastructure systems. This study empirically examines the effect of sustainable urban infrastructure practices on urban resilience in Abuja, Nigeria. Sustainable urban infrastructure was operationalised through green building practices, renewable energy integration, sustainable transportation, smart-city technologies, and resilient infrastructure and disaster-management practices, while urban resilience constituted the dependent variable. A quantitative research design was adopted, using a structured questionnaire administered to respondents in Abuja. Of the 384 questionnaires distributed, 361 were retrieved, while 348 valid responses were analysed using descriptive statistics, Pearson Product-Moment Correlation, and multiple regression analysis. The findings indicate that resilient infrastructure and disaster-management practices recorded the highest mean score (3.71), whereas smart-city technologies recorded the lowest (3.31). The overall mean for sustainable infrastructure was 3.51, compared with 3.39 for urban resilience. Correlation analysis revealed positive associations between all dimensions of sustainable infrastructure and urban resilience, with resilient infrastructure recording the strongest relationship ($r = 0.674$). The regression model produced an R^2 of 0.610, indicating that the five infrastructure dimensions jointly explained 61.0% of the variation in urban resilience. Resilient infrastructure was the strongest predictor ($\beta = 0.337$), followed by renewable energy ($\beta = 0.229$), green building ($\beta = 0.196$), smart-city technologies ($\beta = 0.174$), and sustainable transportation ($\beta = 0.151$). The study concludes that sustainable urban infrastructure significantly enhances urban resilience in Abuja and recommends integrating resilience principles into urban infrastructure planning, investment, and management.

Keywords: Sustainable urban infrastructure; Urban resilience; Green buildings; Smart-city technologies; Abuja

1. INTRODUCTION

Urbanisation has become a defining feature of contemporary development, with cities increasingly functioning as centres of population concentration, economic production, innovation and social interaction. The rapid expansion of urban areas, however, has generated substantial pressure on infrastructure systems and the natural environment. Increasing demand for energy, water, transportation, housing, communication and other essential services has occurred alongside environmental degradation, resource consumption and exposure to climate-related hazards (McGranahan, Schensul & Singh, 2016).

The challenge confronting contemporary cities is therefore no longer limited to the provision of additional infrastructure. Rather, infrastructure must be developed in ways that are environmentally sustainable, economically viable, technologically responsive and capable of functioning under changing conditions. Inclusive and sustainable urbanisation requires consideration of the social, economic and environmental consequences of urban growth, particularly in developing countries where infrastructure provision often struggles to keep pace with population growth (McGranahan, Schensul & Singh, 2016).

Infrastructure plays a fundamental role in urban development by supporting accessibility, economic activity, employment and the provision of essential services. However, conventional infrastructure systems can generate considerable environmental pressures through energy consumption, resource depletion and greenhouse-gas emissions. Consequently, contemporary urban development increasingly emphasises infrastructure that is sustainable, resilient and adaptable to changing environmental and socio-economic conditions (Bibri, 2023). Bibri (2023) particularly highlights the growing relevance of data-driven and technologically enabled approaches to sustainable urban development.

Urban resilience has consequently become an important dimension of sustainable urban development. It refers to the ability of an urban system to withstand disturbances, absorb shocks, maintain essential functions, adapt to changing circumstances and recover following disruptive events. Resilience is particularly important because urban infrastructure systems are interconnected. Disruption to electricity, transportation, water, communication or drainage infrastructure may generate cascading consequences across other components of the urban system (Linkov & Trump, 2019).

The importance of resilience has been reinforced by climate change and increasing exposure to extreme environmental events. Hill and Martinez-Diaz, (2020) argue that existing infrastructure was largely designed around historical climatic conditions and may therefore be insufficient for emerging climate-related extremes. They emphasise the importance of changing building practices, infrastructure standards and land-use decisions to strengthen resilience.

Sustainable urban infrastructure provides an important pathway for strengthening urban resilience. Green buildings, renewable energy systems, sustainable transportation, smart-city technologies and resilient infrastructure can improve resource efficiency, reduce vulnerability and enhance the capacity of urban systems to respond to shocks. Green infrastructure, for example, has increasingly been incorporated into urban development and climate-risk management, although its implementation can also generate social and spatial tensions (Anguelovski, Irazábal-Zurita & Connolly, 2019).

Transportation is similarly important because urban mobility supports access to employment, services, markets and emergency facilities. Pojani and Stead (2015) demonstrate the significance of sustainable transportation in developing-world cities, particularly as rapid urban growth increases mobility demand. Smart-city technologies also provide opportunities for improved infrastructure monitoring, information management and resource optimisation. Kitchin, Cardullo & Di Feliciantonio (2019), however, caution that smart-city development should also consider citizenship, justice, participation and the public good.

These issues are particularly relevant to Abuja, Nigeria's Federal Capital. The continued expansion of Abuja has generated increasing demand for transportation, electricity, water, drainage, communication and other infrastructure services. The ability of the city to accommodate further growth while maintaining reliable services and responding effectively to environmental and socio-economic disruptions is consequently an important planning concern. Despite increasing scholarly attention to sustainable infrastructure and urban resilience, there remains limited empirical evidence on the extent to which specific sustainable infrastructure practices influence urban resilience within the Abuja context. Much of the existing literature focuses on conceptual frameworks, individual infrastructure systems or international experiences. For example, Bozza, Asprone, Parisi & Manfredi (2017) developed resilience indices for assessing urban systems exposed to natural hazards, demonstrating the importance of considering urban resilience as a systemic phenomenon. Spaans & Waterhout (2017) similarly demonstrate the importance of systemic governance and adaptive capacity in developing resilient cities. This study therefore addresses the empirical gap by examining the effect of sustainable urban infrastructure practices on urban resilience in Abuja.

2. LITERATURE REVIEW

2.1 Concept of Sustainable Urban Infrastructure

Sustainable urban infrastructure refers to infrastructure systems that are planned, designed, constructed and managed to satisfy present urban needs while conserving resources and maintaining the capacity of the urban system to function in the future. It incorporates environmental efficiency, economic viability, technological innovation, adaptability and social considerations (Kitchin, Cardullo & Di Feliciantonio, 2019).

The concept recognises that urban infrastructure systems are interconnected. Energy, water, transportation, buildings, communication and waste systems do not operate independently; rather, their performance affects the functionality of the broader urban system. Sustainable infrastructure therefore requires an integrated rather than fragmented approach to urban development.

Bibri (2023) argues that sustainable urban development is increasingly influenced by data-driven and technology-enabled systems capable of improving resource efficiency and urban management. Such approaches are particularly important as cities face increasing pressures arising from population growth, environmental degradation and climate change. Sustainable urban infrastructure can therefore be viewed as infrastructure that simultaneously supports urban functionality, environmental sustainability and long-term adaptability.

2.2 Concept of Urban Resilience

Urban resilience refers to the capacity of an urban system to absorb disturbances while maintaining essential functions and subsequently adapting and recovering. It therefore encompasses resistance, response, recovery and adaptation. Linkov & Trump (2019) conceptualise resilience as particularly relevant to complex and interconnected systems in which disturbances can propagate across multiple components. This perspective is important for cities because infrastructure systems such as transportation, energy, water and communication are interdependent.

Spaans and Waterhout (2017) similarly associate urban resilience with the capacity of cities to respond to acute and chronic challenges, including climate change, environmental degradation, economic pressures and social challenges. Their study of Rotterdam demonstrates the importance of governance and systemic capacity in strengthening urban resilience. Bozza, Asprone, Parisi & Manfredi (2017) further demonstrate that urban resilience can be quantitatively assessed by considering the functioning, vulnerability and recovery of interconnected urban systems.

2.3 Sustainable Urban Infrastructure and Urban Resilience

The relationship between sustainable infrastructure and urban resilience is based on the proposition that infrastructure systems designed for efficiency, adaptability and environmental sustainability are better positioned to withstand disruptions. Resilient infrastructure should not only withstand hazards but should also maintain critical functions and facilitate rapid recovery. Linkov & Trump (2019) emphasise that resilience is particularly important for complex infrastructure networks because failures can have systemic consequences.

Sustainable infrastructure can strengthen resilience through several mechanisms. Green buildings can reduce energy and water demand; renewable energy can diversify energy supply; sustainable transportation can maintain mobility; smart technologies can improve monitoring and response; and resilient infrastructure can reduce physical vulnerability to hazards.

2.4 Green Building Practices and Urban Resilience

Green building practices involve the incorporation of energy efficiency, water conservation, sustainable materials, waste minimisation and environmentally responsive design into buildings. The resilience value of green buildings lies partly in their ability to reduce dependence on external resources. Energy-efficient buildings reduce energy demand, while water-efficient systems reduce pressure on municipal water infrastructure. Climate-responsive design and resilient construction materials may also reduce vulnerability to environmental hazards.

2.5 Renewable Energy Integration and Urban Resilience

Renewable energy integration involves incorporating renewable energy sources such as solar and other sustainable energy systems into urban infrastructure (Kammen & Sunter, 2016). Energy is a critical urban service because electricity disruptions can affect residential, commercial, institutional, healthcare, communication and transportation systems. Consequently, diversifying energy supply can strengthen urban resilience (Hachem-Vermette & Yadav, 2023). Renewable energy can contribute to resilience by reducing dependence on centralised energy systems and providing alternative sources of power for critical facilities (Kostenko & Zaporozhets, 2023). The integration of decentralised energy systems may therefore improve the continuity of essential services during infrastructure disruptions (Hachem-Vermette & Yadav, 2023).

2.6 Sustainable Transportation and Urban Resilience

Transportation infrastructure provides the physical connectivity required for movement of people, goods and services. Sustainable transportation seeks to improve mobility while reducing environmental impacts and resource consumption (Kostenko & Zaporozhets, 2023). Pojani and Stead (2015) highlight the importance of sustainable transportation in developing-world cities where population growth and urban expansion generate increasing mobility requirements.

Transportation is also important for resilience because emergency response, access to essential services and movement of resources depend upon reliable mobility systems (McGranahan, Schensul & Singh, 2016). Sustainable public transportation, pedestrian facilities and integrated mobility systems can therefore strengthen the capacity of urban areas to function during both normal and disruptive conditions.

2.7 Smart-City Technologies and Urban Resilience

Smart-city technologies involve the use of information and communication technologiesc, sensors, digital platforms, data analytics and related technologies to improve urban management (Vodák, Šulyová & Kubina, 2021).

Bibri (2023) argues that data-driven technologies provide opportunities for integrating technological innovation with sustainable urban development. Smart technologies can improve infrastructure monitoring, traffic management, energy management, emergency communication and service delivery. However, technological development alone does not guarantee urban resilience. Kitchin, Cardullo & Di Feliciantonio (2019) emphasise that smart-city initiatives should also consider social justice, citizenship, participation and the public interest. The resilience contribution of smart technologies therefore depends on their effective integration with physical infrastructure, institutional capacity and urban governance.

2.8 Resilient Infrastructure and Disaster Management

Resilient infrastructure and disaster management directly address the capacity of cities to withstand hazards and recover from disruptive events. They include drainage systems, flood-management measures, emergency-response systems, reliable utilities, infrastructure maintenance and disaster-preparedness mechanisms. Bozza, Asprone, Parisi, & Manfredi (2017) demonstrate that infrastructure connectivity and recovery processes are important components of urban resilience. This dimension is particularly relevant to Abuja because infrastructure failures and environmental disturbances can disrupt economic activities and essential services. Strengthening drainage, flood management, infrastructure maintenance and emergency response can therefore enhance the resilience of the city.

3. MATERIAL AND METHODS

The study adopted a quantitative cross-sectional research design to empirically examine the relationship between sustainable urban infrastructure and urban resilience in Abuja, Nigeria. The design was considered appropriate because the study seeks to measure perceptions of infrastructure practices and statistically determine their relationship with urban resilience.The study targeted relevant urban stakeholders and residents within Abuja who possess experience or knowledge of urban infrastructure and service delivery. A sample of 384 respondents was adopted for the study. A structured questionnaire was used as the principal instrument for data collection. The instrument consisted of statements measuring the five dimensions of sustainable urban infrastructure and indicators of urban resilience using a five-point Likert scale.

4. RESULTS AND DISCUSSION

4.1 Response Rate

Table 1: Response Rate

Questionnaire	Frequency	Percentage
Administered	384	100.0
Retrieved	361	94.0
Valid	348	90.6
Invalid/Incomplete	13	3.4
Not Retrieved	23	6.0

The study achieved a high retrieval rate, with 361 of the 384 questionnaires administered successfully retrieved, representing 94.0% of the total. Of these, 348 questionnaires (90.6%) were valid and suitable for statistical analysis, while 13 (3.4%) were incomplete or invalid Table 1. The high valid response rate provides an adequate basis for the subsequent statistical analysis.

4.2 Reliability Analysis

Table 2. Reliability Analysis

Construct	Number of Items	Cronbach's Alpha
Green Building Practices	5	0.812

Construct	Number of Items	Cronbach's Alpha
Renewable Energy Integration	5	0.846
Sustainable Transportation	5	0.801
Smart-City Technologies	5	0.834
Resilient Infrastructure/Disaster Management	5	0.857
Urban Resilience	6	0.879
Overall Instrument	**31**	**0.872**

The Cronbach's alpha coefficients ranged from 0.801 to 0.879, exceeding the commonly accepted threshold of 0.70 Table 2. The overall instrument recorded a reliability coefficient of 0.872, indicating high internal consistency among the 31 measurement items. The instrument was therefore considered sufficiently reliable for the empirical analysis.

4.3 Descriptive Statistics of Sustainable Infrastructure

Table 3: Descriptive Statistics

Variable	Mean	Std. Deviation	Rank
Resilient Infrastructure/Disaster Management	3.71	0.74	1
Green Building Practices	3.58	0.77	2
Renewable Energy Integration	3.52	0.81	3
Sustainable Transportation	3.44	0.79	4
Smart-City Technologies	3.31	0.86	5
Overall Sustainable Infrastructure	**3.51**	**0.79**	

Resilient infrastructure and disaster-management practices recorded the highest mean score (3.71), followed by green building practices (3.58) and renewable energy integration (3.52) Table 3. Smart-city technologies recorded the lowest mean score (3.31), although all dimensions exceeded the neutral midpoint. The overall mean of 3.51 indicates a relatively high level of sustainable urban infrastructure practices.

Table 4: Urban Resilience

Indicator	Mean	Std. Deviation
Infrastructure reliability	3.48	0.82
Continuity of essential services	3.41	0.84
Capacity to withstand disruptions	3.37	0.86

Indicator	Mean	Std. Deviation
Recovery capacity	3.29	0.88
Adaptability	3.43	0.81
Disaster preparedness	3.34	0.87
Overall Urban Resilience	**3.39**	**0.85**

Infrastructure reliability recorded the highest mean score (3.48), followed by adaptability (3.43) and continuity of essential services (3.41) Table 4. Recovery capacity recorded the lowest mean score (3.29), suggesting comparatively weaker perceptions regarding the ability to recover following disruptions. The overall mean of 3.39 indicates a moderate level of urban resilience.

Pearson Correlation Analysis

Table 5: Pearson Correlation Matrix

Variables	UR	GB	RE	ST	SCT	RI
Urban Resilience (UR)	1.000					
Green Building (GB)	.548**	1.000				
Renewable Energy (RE)	.596**	.482**	1.000			
Sustainable Transportation (ST)	.521**	.463**	.437**	1.000		
Smart Technologies (SCT)	.563**	.451**	.508**	.474**	1.000	
Resilient Infrastructure (RI)	.674**	.527**	.562**	.518**	.549**	1.000

Note: **$p < 0.01$.

The results in Table 5 indicate positive and statistically significant relationships between all dimensions of sustainable urban infrastructure and urban resilience. Resilient infrastructure recorded the strongest relationship with urban resilience ($r = 0.674$), followed by renewable energy integration ($r = 0.596$) and smart-city technologies ($r = 0.563$). The findings suggest that improvements in sustainable infrastructure practices are associated with corresponding improvements in urban resilience.

The ANOVA result Table 6 demonstrates that the regression model is statistically significant ($F = 101.42$, $p < 0.001$), indicating that the independent variables jointly have a significant effect on urban resilience. The regression sum of squares is substantially greater than the residual sum of squares, indicating considerable explanatory power. The null hypothesis of no significant combined effect is therefore rejected.

Table 6: ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	145.682	5	29.136	101.42	<0.001
Residual	93.213	342	0.272		
Total	238.895	347			

All five predictors have positive and statistically significant effects on urban resilience. Resilient infrastructure records the strongest standardised effect ($\beta = 0.337$), followed by renewable energy ($\beta = 0.229$), green building practices ($\beta = 0.196$), smart-city technologies ($\beta = 0.174$) and sustainable transportation ($\beta = 0.151$). This indicates that strengthening each dimension of sustainable urban infrastructure is associated with improved urban resilience, with resilient infrastructure and disaster-management practices emerging as the most influential predictor.

5. CONCLUSION

The study concludes that sustainable urban infrastructure practices significantly influence urban resilience in Abuja, with the five dimensions collectively explaining 61.0% of the variation in resilience. Resilient infrastructure and disaster-management practices emerged as the strongest predictor, followed by renewable energy integration, green building practices, smart-city technologies and sustainable transportation. The findings demonstrate that strengthening sustainable infrastructure is critical to improving Abuja's capacity to withstand, adapt to and recover from urban disruptions.

6. RECOMMENDATIONS

Based on the findings, the study recommends that Abuja's urban authorities should prioritise resilient infrastructure, effective drainage, disaster-preparedness systems and infrastructure maintenance in urban development planning. Greater investment should also be directed towards renewable energy systems and green building practices to improve resource efficiency and reduce infrastructure vulnerability. Furthermore, smart-city technologies and sustainable transportation should be integrated into urban infrastructure planning to strengthen infrastructure monitoring, service reliability, mobility and emergency response. Finally, resilience assessment should be incorporated into infrastructure investment and development decisions to ensure that future urban growth in Abuja is sustainable, adaptable and capable of responding to emerging environmental and socio-economic risks.

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