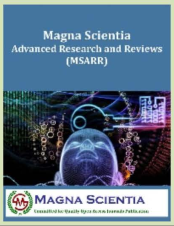
Magna Scientia Advanced Research and Reviews

eISSN: 2582-9394

Cross Ref DOI: 10.30574/msarr

Journal homepage: https://magnascientiapub.com/journals/msarr/



(Review Article)

Check for updates

Future cities and sustainable development: Integrating renewable energy, advanced materials, and civil engineering for urban resilience

Rasheed O. Ajirotutu [1,*], Abiodun Benedict Adeyemi [2], Gil-Ozoudeh Ifechukwu [3], Obinna Iwuanyanwu [4], Tochi Chimaobi Ohakawa [5] and Baalah Matthew Patrick Garba

[1] *Independent Researcher, New York, USA.*
[2] *Coupons Retail Ltd, Lagos. Nigeria.*
[3] *Department of Architecture, Enugu State University of Science and Technology.*
[4] *Independent Researcher, Delta State, Nigeria.*
[5] *Independent Researcher, Washington DC, USA.*
[6] *Cypress & Myrtles Real Estate Limited, Abuja, Nigeria.*

Magna Scientia Advanced Research and Reviews, 2024, 12(02), 235–250

Publication history: Received on 31 October 2024; revised on 04 December 2024; accepted on 07 December 2024

Article DOI: https://doi.org/10.30574/msarr.2024.12.2.0204

Abstract

This review focuses on the integration of renewable energy, advanced materials, and civil engineering to foster urban resilience in future cities. As urban populations continue to grow, the demand for sustainable solutions to mitigate environmental impact and enhance quality of life becomes increasingly urgent. This review explores how the convergence of renewable energy sources, innovative materials, and civil engineering practices can contribute to the development of resilient cities capable of meeting the challenges of the 21st century. The integration of renewable energy sources, such as solar, wind, and hydroelectric power, offers opportunities to reduce dependence on fossil fuels and mitigate greenhouse gas emissions. Advancements in renewable energy technologies allow for the generation of clean, reliable energy within urban environments, promoting energy independence and reducing carbon footprints. Additionally, the utilization of advanced materials in urban infrastructure can enhance durability, efficiency, and sustainability. Nanotechnology, for example, enables the development of high-performance materials with superior strength, flexibility, and resilience. These materials can be used in construction, transportation, and water management systems to improve infrastructure resilience and longevity. Furthermore, civil engineering plays a crucial role in designing and implementing sustainable urban infrastructure. From green building practices to resilient urban planning, civil engineers are instrumental in creating cities that can withstand environmental hazards and adapt to changing conditions. By integrating renewable energy, advanced materials, and innovative engineering solutions, cities can enhance their resilience to climate change, natural disasters, and other challenges. This review examines case studies and examples of successful integration of renewable energy, advanced materials, and civil engineering in urban development projects worldwide. It also discusses the challenges and opportunities associated with implementing these solutions, including technological barriers, financial considerations, and policy frameworks. The integration of renewable energy, advanced materials, and civil engineering is essential for building resilient and sustainable cities of the future. By embracing innovation and collaboration across disciplines, cities can enhance their capacity to thrive in the face of environmental, social, and economic challenges, ultimately improving the quality of life for urban residents while preserving the planet for future generations.

Keywords: Future cities; Sustained development; Renewable energy; Advanced materials; Urban Resilience

* Corresponding author: Rasheed O. Ajirotutu.

1. Introduction

The 21st century has witnessed an unprecedented rate of urbanization, with more than half of the world's population now living in cities (Kundu & Pandey, 2020). This rapid urban growth presents both opportunities and challenges for sustainable development. As cities expand, they face increasing pressure on resources, infrastructure, and the environment. In response to these challenges, the concept of sustainable development has gained prominence as a guiding principle for urban planning and development (Ruggerio, 2021). Sustainable development, as defined by the United Nations, is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Sakalasooriya, 2021). It encompasses economic prosperity, social equity, and environmental protection, with the goal of creating resilient, livable, and inclusive cities.

The importance of sustainable development in future cities cannot be overstated. Urban areas are hubs of economic activity, innovation, and cultural exchange, but they also account for a significant share of global energy consumption, greenhouse gas emissions, and waste generation (Stamopoulos et al., 2024). Without sustainable practices, cities risk exacerbating environmental degradation, exacerbating social inequalities, and compromising the well-being of their residents. Future cities must prioritize environmental sustainability to mitigate the impacts of climate change, reduce pollution, and preserve natural resources. By embracing renewable energy, green infrastructure, and low-carbon transportation, cities can minimize their ecological footprint and enhance resilience to environmental hazards.

Sustainable development is inherently linked to social equity and inclusivity (Verma & Singhania, 2023; Eruaga, 2024). Future cities must strive to provide affordable housing, accessible transportation, quality healthcare, and education for all residents, regardless of socio-economic status (Pozoukidou & Angelidou, 2022). Promoting social cohesion and addressing inequalities are essential for fostering vibrant, livable communities. Studies have shown that adopting sustainable architectural solutions, such as those for affordable and youth-targeted housing, can contribute significantly to achieving social equity (Garba et al., 2024; Umana et al., 2024).

Sustainable development is also closely tied to economic prosperity and resilience. By investing in clean technologies, green industries, and sustainable infrastructure, cities can create new economic opportunities, stimulate innovation, and attract investment (Ikram et al., 2021). Additionally, sustainable practices can reduce long-term costs associated with environmental degradation and resource depletion. Future cities must be resilient to a wide range of challenges, including climate change, natural disasters, and economic shocks (Mondal & Palit, 2022; Adelani et al., 2024). By integrating sustainable practices into urban planning and design, cities can enhance their ability to withstand and recover from adverse events. Resilient cities are better equipped to protect the safety and well-being of their residents and maintain essential services during crises.

This review aims to highlight the importance of integrating renewable energy, advanced materials, and civil engineering for sustainable development and urban resilience in future cities. By embracing innovative solutions and collaborative approaches, cities can build a better future for all residents while preserving the planet for future generations (Girard, 2021).

2. Renewable Energy in Future Cities

Renewable energy sources are derived from natural processes that are continuously replenished, making them sustainable alternatives to finite fossil fuels (Kalair et al., 2021). The main sources of renewable energy include: solar energy, wind energy, hydropower, biomass, and geothermal energy.

Renewable energy plays a critical role in promoting urban sustainability by addressing environmental, economic, and social challenges: Renewable energy sources produce minimal greenhouse gas emissions and air pollutants, helping to mitigate climate change and improve air quality in urban areas (Olabi & Abdelkareem, 2022). By reducing reliance on fossil fuels, renewable energy contributes to the preservation of ecosystems and biodiversity. Renewable energy diversifies energy sources and reduces dependence on imported fossil fuels, enhancing energy security for cities. Moreover, decentralized renewable energy systems, such as rooftop solar panels and microgrids, improve resilience to power outages and disruptions.

Investing in renewable energy creates jobs, stimulates economic growth, and attracts investment in local communities. The renewable energy sector offers opportunities for innovation, entrepreneurship, and technological advancement, driving economic development in urban areas. Policies and programs that prioritize renewable energy adoption can further enhance these benefits, as demonstrated in initiatives that address diverse urban and climatic contexts (Umana et al., 2024a; Umana et al., 2024b).

The cost of renewable energy technologies, particularly solar and wind power, has declined significantly in recent years, making them increasingly competitive with conventional energy sources (Timilsina, 2021). By investing in renewable energy, cities can reduce energy costs and achieve long-term savings for residents and businesses. Renewable energy projects, such as community solar programs and energy cooperatives, empower citizens to participate in the transition to clean energy. Community-owned renewable energy initiatives promote social equity, foster local partnerships, and build a sense of ownership among residents.

New York City's "Solarize NYC" initiative aims to increase solar energy adoption by streamlining the solar installation process and providing incentives for residents and businesses. The program has successfully expanded solar capacity, reduced greenhouse gas emissions, and created green jobs. Copenhagen is renowned for its ambitious efforts to become carbon-neutral by 2025 (Hansen and Agger, 2023). The city's offshore wind farms, such as Middelgrunden and Horns Rev, provide clean electricity to meet a significant portion of the city's energy needs. These wind power projects have positioned Copenhagen as a global leader in renewable energy and urban sustainability. Vancouver's hydropower infrastructure, including the Burrard Generating Station and the Cleveland Dam, generates clean, renewable electricity for the city's residents and businesses (Vogel, 2020). Hydropower plays a crucial role in Vancouver's efforts to reduce carbon emissions and achieve its renewable energy targets.

One of the main challenges of renewable energy is its intermittency, as solar and wind power generation fluctuates depending on weather conditions. Developing cost-effective energy storage technologies, such as batteries and pumped hydro storage, is essential to address this challenge and ensure reliable electricity supply (Mahfoud et al., 2023). Integrating renewable energy into existing grid infrastructure requires upgrades and modifications to accommodate variable generation sources. Smart grid technologies, grid modernization, and demand-side management are key strategies to optimize grid integration and maximize renewable energy penetration (Balouch et al., 2022).

Large-scale renewable energy projects, such as solar and wind farms, can have environmental impacts, including habitat disruption and land use conflicts. Implementing careful site selection, environmental assessments, and mitigation measures is crucial to minimize negative impacts and ensure sustainable development. Inconsistent or inadequate policy support can hinder renewable energy deployment and investment. Governments and policymakers need to implement supportive policies, such as renewable energy targets, feed-in tariffs, and tax incentives, to create an enabling environment for renewable energy development (Painuly & Wohlgemuth, 2021; Omaghomi et al., 2024). Addressing such challenges has been highlighted as vital for both economic growth and urban resilience in Sub-Saharan African cities, where local policies often determine outcomes (Umana et al., 2024a).

Continued investment in research and development is essential to drive technological innovation and reduce the cost of renewable energy technologies. Advancements in materials science, energy storage, and grid integration are key to overcoming technical barriers and unlocking the full potential of renewable energy. Renewable energy plays a crucial role in promoting urban sustainability by providing clean, reliable, and affordable energy for future cities. By harnessing the power of renewable energy sources and addressing challenges through innovation and collaboration, cities can build resilient, environmentally-friendly, and prosperous urban environments for generations to come (Nwokolo et al., 2023; Adelani et al., 2024).

2.1. Advanced Materials for Urban Infrastructure

Advanced materials are the backbone of modern technological advancements, offering innovative solutions to various industries, including civil engineering and urban infrastructure development (Berglund et al., 2020). These materials are engineered to possess superior properties such as strength, durability, flexibility, and sustainability, enabling them to outperform traditional materials like concrete, steel, and wood. The utilization of advanced materials in urban infrastructure is revolutionizing the way cities are built and maintained, leading to more resilient, sustainable, and efficient urban environments. Advanced materials can be categorized into several types, including composites, nanomaterials, polymers, ceramics, and smart materials (Saleh, Fadillah & Ciptawati, 2021). Each type offers unique advantages and is tailored to specific applications within civil engineering and urban infrastructure.

Composite materials, made by combining two or more constituent materials with significantly different physical or chemical properties, find extensive applications in civil engineering for their exceptional strength-to-weight ratio and corrosion resistance (Oladele et al., 2020; Ololade, 2024). Reinforced Concrete: Fibre-reinforced polymers (FRP) are increasingly being used to reinforce concrete structures, offering superior corrosion resistance and extended service life compared to traditional steel reinforcement. Used in strengthening and retrofitting existing structures like bridges and buildings, CFRP provides high strength and stiffness while being lightweight.

Nanomaterials, engineered at the nanoscale, exhibit unique mechanical, electrical, and chemical properties, making them ideal for various civil engineering applications (Okafor et al., 2024). Nanomaterial-Enhanced Concrete: Adding nanoparticles like silica fume or carbon nanotubes to concrete improves its mechanical properties, such as compressive strength, durability, and resistance to cracking. Nanotechnology-based coatings protect infrastructure from corrosion, wear, and environmental degradation, prolonging their service life. These strategies also align with enhancing energy efficiency in public buildings by leveraging advanced materials for structural and operational optimization (Garba et al., 2024).

Polymeric materials offer versatility, durability, and ease of processing, making them suitable for a wide range of urban infrastructure applications (Liang & Hota, 2024). Environmentally friendly alternatives to traditional cement-based materials, geopolymers are used in concrete production, reducing carbon emissions and improving durability. Recycled PET is utilized in various infrastructure components like geotextiles, drainage pipes, and noise barriers, promoting sustainability.

Ceramic materials possess excellent mechanical properties, high-temperature resistance, and chemical stability, making them valuable for demanding civil engineering applications. Used in high-temperature applications such as turbine components and thermal barriers, CMCs offer lightweight and thermal shock resistance. With compressive strengths exceeding 150 MPa, UHPC is employed in bridge decks, pavements, and precast elements, enhancing durability and reducing maintenance needs (Graybeal et al., 2020).

Smart materials, capable of responding to external stimuli, offer innovative solutions for monitoring, maintenance, and energy efficiency in urban infrastructure. Incorporating capsules containing healing agents, self-healing concrete repairs cracks autonomously, extending its service life and reducing maintenance costs. SMA actuators are used in structural elements for vibration control, shape morphing, and energy dissipation, enhancing structural resilience and safety. Furthermore, the monitoring of environmental compliance in construction projects, especially in regions like the oil and gas sector, has revealed the growing importance of advanced materials in minimizing environmental impacts (Audu and Umana, 2024).

The Burj Khalifa, the world's tallest skyscraper, utilizes advanced materials extensively in its construction. High-strength concrete, reinforced with steel and glass fiber, provides the necessary structural support. Additionally, the exterior cladding is made of aluminum and stainless steel, ensuring durability and aesthetics. The Millau Viaduct, an engineering marvel, incorporates advanced materials for its construction (Kumar, 2023). The bridge deck consists of UHPC, which offers exceptional strength and durability. Carbon fiber cables provide support, reducing the weight of the structure and minimizing the environmental impact. Masdar City is a sustainable urban development project that prioritizes advanced materials for its infrastructure. Geopolymer concrete, made from industrial by-products, is used for buildings and pavements, reducing carbon emissions and energy consumption. Smart materials are integrated into the city's infrastructure for efficient energy management and waste reduction.

While advanced materials offer significant benefits, several challenges need to be addressed for widespread adoption (Albertus et al., 2021). The initial cost of advanced materials can be higher than traditional materials, limiting their adoption, especially in developing countries. Research is needed to develop cost-effective manufacturing processes and recycling techniques. There is a lack of standardized testing methods and regulations for advanced materials, leading to uncertainty in performance and safety. Collaborative efforts are required to establish industry standards and regulatory frameworks. Despite their superior properties, some advanced materials may exhibit durability issues over time, particularly in harsh environmental conditions. Research is needed to enhance the long-term performance and durability of these materials (Jamaa et al., 2024). The production and disposal of advanced materials can have environmental implications, including carbon emissions and waste generation. Sustainable manufacturing practices and recycling initiatives are essential to minimize the environmental footprint. Integrating advanced materials with existing infrastructure presents challenges due to compatibility issues and construction constraints (Schram et al., 2022). Innovative retrofitting techniques and adaptive strategies are needed to facilitate the incorporation of advanced materials into aging infrastructure.

2.2. Benefits of Advanced Materials for Urban Resilience

Advanced materials offer superior durability and resistance to environmental degradation, reducing the need for frequent repairs and replacements. This enhances the longevity of urban infrastructure, minimizing disruptions and costs associated with maintenance. Utilizing advanced materials improves the resilience of urban infrastructure against natural disasters, extreme weather events, and seismic activities. Reinforced structures withstand higher loads and deformations, ensuring the safety of inhabitants and minimizing damage during adverse conditions (Stepinac et al., 2020). Indigenous architectural practices, when integrated with advanced materials, further enhance resilience by leveraging locally available resources and traditional techniques to suit specific environmental challenges (Umana et al., 2024a).

Many advanced materials promote sustainability by reducing carbon emissions, energy consumption, and resource depletion. Utilizing recycled materials, implementing lightweight designs, and adopting eco-friendly production processes contribute to a more sustainable urban environment. The integration of digital tools in monitoring the environmental performance of advanced materials has further streamlined their adoption in modern infrastructure (Audu et al., 2024).

Advanced materials enable the design and construction of infrastructure with enhanced functionality and efficiency. Lightweight materials reduce dead loads on structures, improving energy efficiency and lowering construction costs. Additionally, smart materials enable real-time monitoring, predictive maintenance, and adaptive responses, optimizing the performance of urban infrastructure. While the initial investment in advanced materials may be higher than traditional materials, the long-term economic benefits outweigh the costs. Reduced maintenance expenses, extended service life, and improved operational efficiency lead to significant cost savings over the lifecycle of urban infrastructure.

Advanced materials play a crucial role in the development of resilient, sustainable, and efficient urban infrastructure. Their utilization in civil engineering applications offers numerous benefits, including enhanced durability, increased resilience, sustainability, improved functionality, and economic savings (Babalola et al., 2023). As cities continue to grow and face challenges posed by climate change and urbanization, advanced materials will be instrumental in shaping the future of urban infrastructure.

2.3. Civil Engineering Solutions for Urban Resilience

As urban populations continue to grow and cities face increasing challenges from climate change, natural disasters, and aging infrastructure, civil engineering plays a pivotal role in developing solutions to enhance urban resilience (Salimi & Al-Ghamdi, 2020; Ogbowuokara et al., 2023). This explores various civil engineering strategies for building sustainable and resilient cities, including the role of civil engineering in sustainable urban development, green building practices, urban planning for resilience, transportation solutions, water management systems, and case studies of civil engineering solutions in future cities.

Civil engineering is essential for sustainable urban development, as it encompasses the planning, design, construction, and maintenance of infrastructure that supports urban life (Álvarez et al., 2021). There are responsible for developing solutions that promote environmental sustainability, social equity, and economic prosperity in urban areas. Sustainable urban development focuses on creating livable, healthy, and resilient cities by integrating principles of environmental conservation, resource efficiency, and social inclusion into infrastructure projects. Civil engineering strategies have also demonstrated the potential to align profitability with environmental compliance, particularly in resource-intensive industries like oil and gas (Umana et al., 2024b).

Green building practices are key components of sustainable infrastructure, focusing on minimizing environmental impact, conserving resources, and enhancing occupant comfort and well-being. Civil engineers incorporate green building principles into the design and construction of infrastructure projects to achieve energy efficiency, water conservation, and waste reduction. Sustainable infrastructure features include: Civil engineers design buildings with features such as efficient insulation, high-performance windows, and energy-efficient HVAC systems to reduce energy consumption and lower carbon emissions (Simpeh et al., 2022; Orikpete, Ikemba & Ewim, 2023). They also incorporate renewable energy sources such as solar panels, wind turbines, and geothermal systems into buildings and infrastructure to generate clean, renewable power and reduce reliance on fossil fuels. Environmental compliance remains a cornerstone in ensuring that these innovations align with both economic and regulatory standards (Audu and Umana, 2024).

Urban planning plays a critical role in enhancing urban resilience by creating resilient, adaptive, and inclusive communities. Civil engineers collaborate with urban planners to develop strategies that integrate resilience principles into land use, zoning, and development policies. Key components of urban planning for resilience include: Civil engineers design mixed-use developments that combine residential, commercial, and recreational spaces within walkable neighborhoods, reducing the need for car travel and promoting social interaction (Baobei, Koç & Al-Ghamdi, 2021). Civil engineers promote compact urban design that minimizes sprawl and preserves open space, reducing land consumption and protecting natural habitats. Infrastructure and buildings that are resilient to climate change impacts such as extreme heat, flooding, and sea-level rise. This includes elevating buildings, installing green roofs, and incorporating natural drainage systems to manage stormwater. Engaging with communities to understand their needs and concerns ensures that infrastructure projects meet the needs of local residents.

Transportation plays a crucial role in urban resilience, as efficient and reliable transportation systems are essential for mobility, economic activity, and emergency response (Ezeafulukwe et al., 2024). Civil engineers develop transportation solutions that improve accessibility, reduce congestion, and minimize environmental impact. Key transportation solutions include: Civil engineers design and expand public transit systems, including buses, trains, and light rail, to provide affordable, convenient, and sustainable transportation options for urban residents. Develop infrastructure for walking and cycling, such as sidewalks, bike lanes, and multi-use trails, to promote active transportation and reduce dependence on cars. Implement ITS technologies, including traffic signal coordination, real-time traffic monitoring, and dynamic routing, to improve traffic flow, reduce congestion, and enhance safety (Ravish & Swamy, 2021). Plan and design TOD projects that integrate public transit with mixed-use development, creating vibrant, pedestrian-friendly neighborhoods with easy access to transit services.

Water management is critical for urban resilience, as cities must manage water resources effectively to ensure a reliable supply of clean water, mitigate flooding, and protect against water-related hazards (Pokhrel et al., 2022). Civil engineers develop water management systems that promote sustainability, efficiency, and resilience. Key water management solutions include: Civil engineers design stormwater management systems, including green infrastructure, retention ponds, and underground storage tanks, to capture, store, and treat stormwater runoff and reduce flooding and pollution. Implement water conservation measures, such as leak detection systems, water-efficient fixtures, and smart irrigation systems, to reduce water consumption and minimize demand on water supplies. Design and operate wastewater treatment plants to treat sewage and industrial wastewater and protect public health and the environment. Advanced treatment technologies such as membrane bioreactors and ultraviolet disinfection are used to remove contaminants and produce high-quality effluent. Floodplain management plans can reduce flood risk and protect property and infrastructure through levees, floodwalls, and stormwater detention basins.

Civil engineering solutions are essential for building sustainable and resilient cities that can withstand and adapt to the challenges of the 21st century. By incorporating green building practices, sustainable infrastructure, urban planning for resilience, transportation solutions, and water management systems, civil engineers can create cities that are healthier, safer (Carpejani et al., 2020).

2.4. Integration of Renewable Energy, Advanced Materials, and Civil Engineering

The integration of renewable energy, advanced materials, and civil engineering is crucial for developing sustainable urban environments that can meet the challenges of the 21st century (Hoang & Nguyen, 2021). This explores the synergies and interconnections between renewable energy, materials, and engineering, collaborative approaches to urban development, best practices and success stories, and challenges and solutions in integration.

Renewable energy, advanced materials, and civil engineering are interconnected in various ways, each contributing to the development of sustainable infrastructure and urban environments. Renewable energy technologies such as solar panels, wind turbines, and geothermal systems rely on advanced materials for their construction and operation. For example, photovoltaic cells use materials such as silicon, cadmium telluride, and perovskites to convert sunlight into electricity. Advanced materials can enhance the efficiency and performance of renewable energy systems (Patel et al., 2020). For instance, lightweight and durable materials can improve the design and durability of wind turbine blades, increasing energy capture and reducing maintenance costs. Civil engineering plays a crucial role in the deployment and integration of renewable energy systems into urban infrastructure. Digital tools, in particular, are proving instrumental in optimizing these integrations for environmental sustainability and operational efficiency (Audu et al., 2024a).

Renewable energy can also be integrated into civil engineering projects to enhance sustainability and resilience. For example, green roofs and solar canopies can be incorporated into building designs to generate renewable energy and reduce energy consumption. Advanced materials play a significant role in civil engineering by improving the performance, durability, and sustainability of infrastructure. For instance, high-performance concrete, fiber-reinforced polymers, and advanced composites are used to enhance the strength and durability of bridges, buildings, and roads. Civil engineering projects often require large quantities of materials, and the choice of materials can have significant environmental and economic impacts. Sustainable materials such as recycled aggregates, fly ash, and bamboo can reduce resource consumption and environmental impact (Ryłko-Polak, Komala & Białowiec, 2022). Innovations in process optimization are critical for ensuring that these material and energy solutions align with the sustainability objectives of emerging markets (Umana et al., 2024b).

Collaborative approaches to urban development involve cooperation between government agencies, private sector stakeholders, research institutions, and communities to create sustainable and resilient cities (Marana et al., 2020). PPPs bring together public and private sector partners to finance, develop, and operate infrastructure projects. In the context of renewable energy, materials, and civil engineering, PPPs can facilitate the deployment of renewable energy projects and the adoption of advanced materials in infrastructure construction. For example, a PPP between a local government, a renewable energy developer, and a construction company could finance and build a solar farm to power municipal buildings, using advanced materials for the solar panels and support structures.

Collaborations between research institutions, universities, and industry can drive innovation in renewable energy, materials, and civil engineering. Joint research projects can develop new technologies, materials, and construction methods to improve the sustainability and resilience of urban infrastructure. For instance, a collaboration between a university research lab, a materials manufacturer, and a civil engineering firm could develop a novel composite material for bridge construction that is lightweight, durable, and resistant to corrosion. Engaging with local communities is essential for successful urban development projects. Community input can help identify priorities, address concerns, and ensure that projects meet the needs of residents. Community-driven initiatives, such as community-owned renewable energy projects or neighborhood revitalization efforts, can empower residents to take ownership of their urban environment and contribute to its sustainability and resilience (Lamb et al., 2023).

Financing mechanisms such as subsidies, tax incentives, and green bonds can help overcome financial barriers and incentivize investment in sustainable infrastructure. Regulatory barriers, including zoning restrictions, building codes, and permitting processes, can hinder the adoption of renewable energy and advanced materials. Governments can streamline regulations, update building codes, and provide incentives for sustainable development to encourage integration. Technological innovation is needed to develop new renewable energy technologies, advanced materials, and engineering solutions that are more efficient, cost-effective, and sustainable (Ebhota & Jen, 2020). Research and development funding, public-private partnerships, and collaboration between industry and academia can drive innovation in these areas.

Public awareness and acceptance of renewable energy, advanced materials, and sustainable infrastructure are essential for successful integration. Education and outreach efforts can help raise awareness about the benefits of sustainable development and build support for initiatives such as renewable energy projects and green building practices. The integration of renewable energy, advanced materials, and civil engineering is essential for building sustainable and resilient urban environments. By leveraging synergies between these disciplines and adopting collaborative approaches to urban development, cities can address the challenges of climate change, resource scarcity, and urbanization while enhancing quality of life and promoting economic prosperity (Garg et al., 2024; Adaga et al., 2024).

2.5. Implications and Benefits

Renewable energy, advanced materials, and civil engineering play vital roles in shaping the sustainability and resilience of modern cities (Soliman et al., 2022). Their integration offers a wide array of benefits across environmental, economic, and social dimensions, while also enhancing resilience to climate change and natural disasters. Renewable energy sources such as solar, wind, and hydroelectric power produce electricity without emitting greenhouse gases, unlike fossil fuels. By transitioning to renewables, cities can significantly reduce their carbon footprint and mitigate climate change. The use of renewable energy and advanced materials in infrastructure reduces air pollution compared to conventional energy sources and materials. This leads to cleaner air and improved public health, as fewer harmful pollutants are released into the atmosphere. Renewable energy sources are inexhaustible and abundant, unlike finite fossil fuel reserves. By harnessing renewable energy, cities can reduce their dependence on non-renewable resources and preserve natural ecosystems from the impacts of resource extraction. Advanced materials and engineering techniques promote recycling, reuse, and waste reduction in construction and infrastructure projects (Mohammed et al., 2020). This reduces the amount of waste sent to landfills and lowers the environmental impact of urban development.

The renewable energy sector generates employment opportunities in manufacturing, installation, maintenance, and operation of renewable energy systems. Similarly, the adoption of advanced materials in construction creates jobs in material production, design, and construction industries (Umoh et al., 2024). Renewable energy systems offer long-term cost savings compared to fossil fuels, as they have lower operating and maintenance costs and are not subject to price volatility. Additionally, energy-efficient buildings and infrastructure reduce energy consumption, leading to lower utility bills for residents and businesses. The transition to renewable energy and sustainable infrastructure presents lucrative investment opportunities for businesses, governments, and investors. Renewable energy projects, green buildings, and infrastructure upgrades attract investment and stimulate economic growth (Moşteanu, 2020). Cities that embrace renewable energy and advanced materials gain a competitive edge in the global market. They attract businesses, talent, and investment, positioning themselves as leaders in sustainability and innovation.

Reduced air pollution from renewable energy and sustainable infrastructure improves public health outcomes by lowering rates of respiratory diseases and cardiovascular illnesses. Cleaner air enhances the overall well-being of urban residents. Sustainable urban environments with green spaces, energy-efficient buildings, and reliable infrastructure contribute to a higher quality of life for residents (Grace, Iqbal & Rabbi, 2023). Access to clean energy, safe water, and efficient transportation improves living standards and promotes social equity. The adoption of renewable energy and sustainable infrastructure encourages community engagement and participation in urban development. Residents become actively involved in sustainability initiatives, fostering a sense of ownership and pride in their city. Renewable energy and sustainable infrastructure promote equitable access to essential services such as energy, water, and transportation. By reducing energy costs and improving access to clean water and efficient transportation, marginalized communities can benefit from sustainable development (Kılkış et al., 2022).

Renewable energy and sustainable infrastructure enhance cities' resilience to climate change by reducing greenhouse gas emissions and mitigating the impacts of extreme weather events (Sharifi, 2021). Resilient infrastructure withstands floods, storms, and heatwaves, protecting lives and property. Advanced materials and civil engineering solutions enable the development of adaptive infrastructure that can respond to changing environmental conditions. Climate-resilient buildings, flood barriers, and green infrastructure are designed to adapt to rising sea levels, increased temperatures, and more frequent extreme weather events (Siehr, Sun & Aranda Nucamendi, 2022). Sustainable urban development improves cities' preparedness for natural disasters by integrating disaster-resistant design principles. Earthquake-resistant buildings, flood-proof infrastructure, and early warning systems help cities mitigate the impacts of disasters and minimize loss of life and property damage. Renewable energy sources such as solar and wind power enhance cities' energy security by diversifying the energy mix and reducing reliance on imported fossil fuels. Local renewable energy generation ensures a reliable and resilient energy supply, even during disruptions to the grid. The integration of renewable energy, advanced materials, and civil engineering offers numerous benefits across environmental, economic, and social domains. By reducing carbon emissions, improving air quality, creating jobs, and enhancing quality of life, sustainable urban development promotes resilience to climate change and natural disasters while fostering economic growth and social equity (Shi et al., 2022). Embracing these integrated technologies and practices is essential for building cities that are sustainable, resilient, and inclusive in the face of global challenges.

2.6. Challenges and Considerations

As cities strive to adopt renewable energy, advanced materials, and innovative civil engineering practices to enhance sustainability and resilience, they face various challenges and considerations (Murtagh, Scott & Fan, 2020). This explores the technological challenges, financial considerations, policy and regulatory frameworks, and the importance of public awareness and engagement in the integration process. One of the primary challenges of renewable energy sources like solar and wind is their intermittency. The generation of solar power is dependent on sunlight availability, while wind power is influenced by wind speed and direction. Developing energy storage solutions and smart grid technologies to manage this intermittency is crucial. The development of advanced materials suitable for sustainable infrastructure faces challenges related to cost, scalability, and performance. Research and development efforts are needed to overcome these challenges and produce materials that are durable, cost-effective, and environmentally friendly. Integrating renewable energy, advanced materials, and civil engineering solutions requires interdisciplinary collaboration and coordination. Ensuring compatibility and synergy between different technologies poses technical challenges that must be addressed to achieve optimal performance and efficiency. Effective management and analysis of data are essential for optimizing the performance of renewable energy systems, monitoring infrastructure health, and informing decision-making processes (Manfren et al., 2020). Cities need robust data infrastructure and analytics tools to collect, analyze, and utilize data effectively. The upfront costs of implementing renewable energy, advanced materials, and innovative civil engineering solutions can be significant. Cities may face challenges in securing financing for infrastructure projects, especially in the absence of sufficient capital or access to affordable financing options. Demonstrating the economic viability and long-term benefits of sustainable infrastructure investments is essential for attracting financial support. Cities must assess the ROI of renewable energy projects, considering factors such as energy savings, operational costs, and environmental benefits. Limited access to funding and investment resources can hinder the adoption of renewable energy and sustainable infrastructure. Cities need access to grants, subsidies, loans, and private investment to finance projects and overcome financial barriers. Developing and deploying innovative technologies and materials may incur additional costs compared to conventional solutions (Sharma, Chehri & Fortier, 2021). Cities must balance the cost of innovation with the expected benefits and prioritize investments that offer the greatest potential for long-term sustainability and resilience.

Inconsistent or outdated policies and regulations can create uncertainty and hinder the adoption of renewable energy and sustainable infrastructure (Durani et al., 2023). Cities need clear and supportive policy frameworks that incentivize investment, streamline permitting processes, and facilitate technology deployment. Regulatory barriers, such as zoning restrictions, building codes, and utility regulations, can impede the integration of renewable energy and sustainable infrastructure. Cities must work with governments and regulatory agencies to address these barriers and create an enabling environment for innovation. Achieving policy alignment and coordination across different levels of government is essential for effective urban development (Croese et al., 2021). Cities must collaborate with national and regional authorities to harmonize policies, set ambitious targets, and ensure consistency in regulatory frameworks. Engaging stakeholders, including government agencies, industry partners, and community organizations, in the policy-making process is crucial for building consensus and driving change. Cities must involve stakeholders in policy development, implementation, and evaluation to ensure buy-in and support.

Many members of the public may lack awareness of the benefits of renewable energy and sustainable infrastructure, as well as the importance of adopting these technologies for building resilient cities. Cities must invest in education and outreach initiatives to raise awareness and promote understanding among residents. Public acceptance of renewable energy projects and sustainable infrastructure developments can be challenging, especially in cases where residents have concerns about visual impact, noise, or property values (Beer. Rybár & Gabániová, 2023). Cities must address community concerns through transparent communication, stakeholder engagement, and participatory decision-making processes. Building the capacity of local communities, businesses, and government agencies to adopt and implement renewable energy and sustainable infrastructure solutions is essential. Cities can provide training, resources, and incentives to empower stakeholders and foster a culture of sustainability. Encouraging behavior change and promoting sustainable lifestyles among residents is critical for achieving lasting impact. Cities must implement awareness campaigns, incentives, and behavioral interventions to encourage energy conservation, waste reduction, and sustainable transportation choices. Addressing the challenges and considerations associated with the integration of renewable energy, advanced materials, and civil engineering requires a holistic approach that encompasses technological innovation, financial planning (Orikpete, Leton & Momoh, 2022)

2.7. Case Studies: Examining Sustainable Urban Development

Sustainable urban development is a global imperative, and numerous cities around the world have embarked on ambitious projects to integrate renewable energy, advanced materials, and innovative civil engineering practices. This examines three notable case studies: Masdar City in the UAE, Songdo International Business District in South Korea, and Copenhagen in Denmark. Through these examples, we'll explore the strategies, challenges, and lessons learned in implementing sustainable urban development initiatives.

Masdar City, located in Abu Dhabi, UAE, is one of the world's most ambitious sustainable urban development projects (Sankaran & Chopra, 2020). Initiated in 2006 by the Abu Dhabi Future Energy Company (Masdar), the city aims to be a model for sustainable living and innovation. Masdar City aims to be carbon-neutral and powered entirely by renewable energy sources. The city utilizes solar panels, wind turbines, and geothermal energy to generate clean electricity. The city incorporates advanced materials in its construction, such as sustainable building materials, energy-efficient glass, and smart building technologies. Masdar City features a smart grid system that monitors and optimizes energy use, as well as smart transportation systems like automated electric shuttles and a Personal Rapid Transit (PRT) system.

Masdar City faced challenges in securing funding for its ambitious vision, particularly during the global financial crisis. The project scaled back some of its initial plans due to financial constraints. Despite its innovative design and technology, Masdar City's scale remains relatively small compared to initial plans. Its development has been slower than anticipated, with only a fraction of the envisioned population currently residing there. Masdar City learned the importance of taking an incremental approach to sustainable development (Griffiths & Sovacool, 2020). While the original vision was ambitious, the city adapted its plans to scale and focused on achievable goals. The involvement of private sector partners and government support has been crucial for the success of Masdar City. PPPs have provided financing, expertise, and technological innovation to the project.

Songdo International Business District (IBD), located in Incheon, South Korea, is a planned city built on reclaimed land along the Yellow Sea coast. It is designed to be a sustainable, green, and smart city of the future (Eireiner, 2021). Songdo IBD incorporates extensive green spaces, parks, and landscaped areas, promoting biodiversity and improving air quality. The city features energy-efficient buildings with green roofs, solar panels, and advanced insulation to reduce energy consumption. Songdo IBD utilizes smart technologies for energy management, waste collection, and transportation. It has an extensive network of sensors and communication systems to monitor and optimize city operations.

Songdo IBD faced challenges in cultural adoption, as it was initially slow to attract residents and businesses. The city had to overcome perceptions of being artificial and lacking in character. Despite substantial investment, Songdo IBD has struggled to achieve its intended economic success. It has faced competition from nearby cities like Seoul and challenges in attracting major corporations. Songdo IBD learned the importance of mixed-use development to create vibrant, walkable neighborhoods (Wheeler, 2022). Integrating residential, commercial, and recreational spaces fosters a sense of community and livability. The city learned the importance of adaptive planning and flexibility in responding to changing market demands. It has adjusted its development strategy to focus more on residential and cultural amenities.

Copenhagen, the capital of Denmark, is widely regarded as one of the world's most sustainable cities (Krähmer, 2021). It has implemented numerous initiatives to reduce carbon emissions, improve energy efficiency, and enhance livability. Copenhagen is famous for its extensive cycling infrastructure, including dedicated bike lanes, bike-sharing programs, and cyclist-friendly traffic policies. The city has committed to becoming carbon-neutral by 2025 and is investing in renewable energy sources such as wind power and district heating systems. Copenhagen prioritizes green spaces and urban parks, providing residents with access to nature and promoting physical and mental well-being. Copenhagen faces challenges related to urban growth and densification, as the city's population continues to grow. Balancing development with preservation of green spaces and historic neighborhoods is a constant challenge. Despite its efforts, Copenhagen is vulnerable to the impacts of climate change, including sea-level rise and extreme weather events (Muis et al., 2020). The city must invest in adaptive measures to enhance resilience. Copenhagen has learned the importance of community engagement in sustainable development. The city actively involves residents in decision-making processes and encourages participation in sustainability initiatives

3. Conclusion

In this review, we have explored the integration of renewable energy, advanced materials, and civil engineering in the context of sustainable urban development. Through case studies, challenges, and considerations, we have gained insights into the importance of these integrated approaches for building resilient and sustainable cities of the future. The integration of renewable energy, advanced materials, and civil engineering is essential for addressing the complex challenges faced by modern cities. Sustainable urban development generates economic opportunities, creates jobs, and attracts investment, contributing to long-term economic growth and prosperity. Sustainable cities promote social equity, enhance quality of life, and foster community engagement, ensuring that urban development is inclusive and equitable. Integrating renewable energy and advanced materials enhances cities' resilience to climate change and natural disasters, protecting lives and infrastructure.

The integration of renewable energy, advanced materials, and civil engineering is critical for the development of future cities. As urban populations continue to grow, and environmental challenges escalate, cities must embrace sustainable and resilient solutions to meet the needs of present and future generations. Integrated approaches offer a holistic framework for addressing environmental, economic, and social challenges, ensuring that cities are not only sustainable but also adaptable to changing conditions. To achieve sustainable urban development, collaboration and concerted action are needed from various stakeholders, including governments, businesses, communities, and academia. Governments must enact supportive policies and regulatory frameworks that incentivize sustainable development, promote innovation, and facilitate investment in renewable energy and advanced materials. Increasing public awareness and engagement is crucial for fostering a culture of sustainability. Education, outreach programs, and public campaigns can empower citizens to adopt sustainable practices and support green initiatives. Collaboration between governments, private sector companies, research institutions, and communities is essential for driving innovation and implementing integrated solutions. Public-private partnerships and international collaborations can accelerate progress towards sustainable development goals. Continued investment in research and development is needed to advance renewable energy technologies, develop new materials, and enhance engineering practices. Research institutions and universities play a vital role in driving innovation and knowledge transfer.

While significant progress has been made in sustainable urban development, several areas warrant further research and exploration: Investigating circular economy principles in urban development can lead to more efficient resource use, waste reduction, and closed-loop systems. Researching the efficacy of nature-based solutions, such as green infrastructure and ecosystem restoration, in enhancing urban resilience and biodiversity. Exploring the integration of emerging technologies, such as artificial intelligence, Internet of Things (IoT), and blockchain, in optimizing urban systems and services for sustainability. Examining strategies to ensure that sustainable development benefits all segments of society, particularly marginalized communities, and addressing issues of social equity and inclusivity. The integration of renewable energy, advanced materials, and civil engineering is essential for building sustainable, resilient, and livable cities. By embracing integrated approaches, leveraging technological innovations, and fostering collaboration, cities can address the challenges of urbanization, climate change, and resource depletion, creating a better future for all. It is imperative that we act now to shape the cities of tomorrow into vibrant, sustainable, and resilient hubs of human activity and progress.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Adaga, E.M., Egieya, Z.E., Ewuga, S.K., Abdul, A.A. and Abrahams, T.O., (2024). Tackling economic inequalities through business analytics: A literature review. Computer Science & IT Research Journal, 5(1), pp.60-80. https://doi.org/10.51594/csitrj.v5i1.702

[2] Adelani, F.A., Okafor, E.S., Jacks, B.S. and Ajala, O.A., (2024). THEORETICAL FRAMEWORKS FOR THE ROLE OF AI AND MACHINE LEARNING IN WATER CYBERSECURITY: INSIGHTS FROM AFRICAN AND US APPLICATIONS. *Computer Science & IT Research Journal*, *5*(3), pp.681-692. https://doi.org/10.51594/csitrj.v5i3.928

[3] Adelani, F.A., Okafor, E.S., Jacks, B.S. and Ajala, O.A., (2024). THEORETICAL INSIGHTS INTO SECURING REMOTE MONITORING SYSTEMS IN WATER DISTRIBUTION NETWORKS: LESSONS LEARNED FROM AFRICA-US PROJECTS. *Engineering Science & Technology Journal*, *5*(3), pp.995-1007. https://doi.org/10.51594/estj.v5i3.953

[4] Albertus, P., Anandan, V., Ban, C., Balsara, N., Belharouak, I., Buettner-Garrett, J., Chen, Z., Daniel, C., Doeff, M., Dudney, N.J. and Dunn, B., (2021). Challenges for and pathways toward Li-metal-based all-solid-state batteries. https://doi.org/10.1021/acsenergylett.1c00445

[5] Álvarez, I., Etxeberria, P., Alberdi, E., Pérez-Acebo, H., Eguia, I. and García, M.J., (2021). Sustainable civil engineering: Incorporating sustainable development goals in higher education curricula. *Sustainability*, *13*(16), p.8967. https://doi.org/10.3390/su13168967

[6] Audu, A.J., and Umana, A.U. (2024). Advances in environmental compliance monitoring in the oil and gas industry: Challenges and opportunities. International Journal of Scientific Research Updates, 8(2), pp.48-59. https://doi.org/10.53430/ijsru.2024.8.2.0062.

[7] Audu, A.J., and Umana, A.U. (2024). The role of environmental compliance in oil and gas production: A critical assessment of pollution control strategies in the Nigerian petrochemical industry. International Journal of Scientific Research Updates, 8(2), pp.36-47. https://doi.org/10.53430/ijsru.2024.8.2.0061.

[8] Audu, A.J., Umana, A.U., and Garba, B.M.P. (2024). The role of digital tools in enhancing environmental monitoring and business efficiency. International Journal of Multidisciplinary Research Updates, 8(2), pp.39-48. https://doi.org/10.53430/ijmru.2024.8.2.0052.

[9] Babalola, F.I., Oriji, O., Oladayo, G.O., Abitoye, O. and Daraojimba, C., (2023). Integrating ethics and professionalism in accounting education for secondary school students. International Journal of Management & Entrepreneurship Research, 5(12), pp.863-878. https://doi.org/10.51594/ijmer.v5i12.622

[10] Balouch, S., Abrar, M., Abdul Muqeet, H., Shahzad, M., Jamil, H., Hamdi, M., Malik, A.S. and Hamam, H., (2022). Optimal scheduling of demand side load management of smart grid considering energy efficiency. *Frontiers in Energy Research*, *10*, p.861571. https://doi.org/10.3389/fenrg.2022.861571

[11] Beer, M., Rybár, R. and Gabániová, Ľ., (2023). Visual impact of renewable energy infrastructure: Implications for deployment and public perception. *Processes*, *11*(8), p.2252. https://doi.org/10.3390/pr11082252

[12] Berglund, E.Z., Monroe, J.G., Ahmed, I., Noghabaei, M., Do, J., Pesantez, J.E., Khaksar Fasaee, M.A., Bardaka, E., Han, K., Proestos, G.T. and Levis, J., (2020). Smart infrastructure: a vision for the role of the civil engineering profession in smart cities. *Journal of Infrastructure Systems*, *26*(2), p.03120001. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000549

[13] Carpejani, G., da Silva Neiva, S., Deggau, A.B. and de Andrade Guerra, J.B.S.O., (2020). Resilient and Green Building Design/Construction. *Sustainable Cities and Communities*, pp.539-545. https://doi.org/10.1007/978-3-319-95717-3_15

[14] Croese, S., Oloko, M., Simon, D. and Valencia, S.C., (2021). Bringing the global to the local: The challenges of multi-level governance for global policy implementation in Africa. *International Journal of Urban Sustainable Development*, *13*(3), pp.435-447. https://doi.org/10.1080/19463138.2021.1958335

[15] Durani, F., Bhowmik, R., Sharif, A., Anwar, A. and Syed, Q.R., (2023). Role of economic uncertainty, financial development, natural resources, technology, and renewable energy in the environmental Phillips curve framework. *Journal of Cleaner Production*, *420*, p.138334. https://doi.org/10.1016/j.jclepro.2023.138334

[16] Ebhota, W.S. and Jen, T.C., (2020). Fossil fuels environmental challenges and the role of solar photovoltaic technology advances in fast tracking hybrid renewable energy system. *International Journal of Precision Engineering and Manufacturing-Green Technology*, *7*, pp.97-117. https://doi.org/10.1007/s40684-019-00101-9

[17] Eireiner, A.V., (2021). Promises of urbanism: New Songdo city and the power of infrastructure. *Space and Culture*, p.12063312211038716. https://doi.org/10.1177/12063312211038716

[18] Eruaga, M.A., (2024). Assessing the role of public education in enhancing food safety practices among consumers. https://doi.org/10.56781/ijsrst.2024.4.1.0023

[19] Ezeafulukwe, C., Owolabi, O.R., Asuzu, O.F., Onyekwelu, S.C., Ike, C.U. and Bello, B.G., (2024). Exploring career pathways for people with special needs in STEM and beyond. International Journal of Applied Research in Social Sciences, 6(2), pp.140-150. https://doi.org/10.51594/ijarss.v6i2.780

[20] Garba, B.M.P., Umar, M.O., Umana, A.U., Olu, J.S., and Ologun, A. (2024). Sustainable architectural solutions for affordable housing in Nigeria: A case study approach. World Journal of Advanced Research and Reviews, 23(03), pp.434-445. DOI: 10.30574/wjarr.2024.23.3.2704. https://doi.org/10.30574/wjarr.2024.23.3.2704

[21] Garba, B.M.P., Umar, M.O., Umana, A.U., Olu, J.S., and Ologun, A. (2024). Energy efficiency in public buildings: Evaluating strategies for tropical and temperate climates. World Journal of Advanced Research and Reviews, 23(03), pp.409-421. https://doi.org/10.30574/wjarr.2024.23.3.2702

[22] Garg, A., Maurya, S.P., Laxmi, M.B., Raut, K.J., Yerasuri, S.S. and Shinde, R.M., (2024). Smart Cities and Smart Supply Chain: Integration for Sustainable Urban Development. *Power System Technology*, *48*(1), pp.239-254. https://doi.org/10.52783/pst.271

[23] Girard, L.F., (2021). The evolutionary circular and human centered city: Towards an ecological and humanistic "re-generation" of the current city governance. *Human Systems Management*, *40*(6), pp.753-775. https://doi.org/10.3233/HSM-211218

[24] Grace, O., Iqbal, K. and Rabbi, F., (2023). Creating Sustainable Urban Environments: The Vital Link between Development, Health, and Smart Cities. *International Journal of Sustainable Infrastructure for Cities and Societies*, *8*(1), pp.53-72. http://vectoral.org/index.php/IJSICS/article/view/6

[25] Graybeal, B., Brühwiler, E., Kim, B.S., Toutlemonde, F., Voo, Y.L. and Zaghi, A., (2020). International perspective on UHPC in bridge engineering. *Journal of Bridge Engineering*, *25*(11), p.04020094. https://doi.org/10.1061/(ASCE)BE.1943-5592.0001630

[26] Griffiths, S. and Sovacool, B.K., (2020). Rethinking the future low-carbon city: Carbon neutrality, green design, and sustainability tensions in the making of Masdar City. *Energy Research & Social Science*, *62*, p.101368. https://doi.org/10.1016/j.erss.2019.101368

[27] Hansen, K.B. and Agger, A., (2023). Copenhagen CO2 neutrality in 2025? A polycentric analysis of urban climate governance in Copenhagen 2006–2020. *Environmental Policy and Governance*, *33*(3), pp.288-300. https://doi.org/10.1002/eet.2030

[28] Hoang, A.T. and Nguyen, X.P., (2021). Integrating renewable sources into energy system for smart city as a sagacious strategy towards clean and sustainable process. *Journal of Cleaner Production*, *305*, p.127161. https://doi.org/10.1016/j.jclepro.2021.127161

[29] Ikram, M., Ferasso, M., Sroufe, R. and Zhang, Q., (2021). Assessing green technology indicators for cleaner production and sustainable investments in a developing country context. *Journal of Cleaner Production*, *322*, p.129090. https://doi.org/10.1016/j.jclepro.2021.129090

[30] Jamaa, G.M., Tian, Y., Xie, Z., Yu, C., Hu, C., Chen, L. and Yuan, Q., (2024). Effect of accelerators on the long-term performance of shotcrete and its improvement strategies: A review. *Journal of Building Engineering*, p.109364. https://doi.org/10.1016/j.jobe.2024.109364

[31] Kalair, A., Abas, N., Saleem, M.S., Kalair, A.R. and Khan, N., (2021). Role of energy storage systems in energy transition from fossil fuels to renewables. *Energy Storage*, *3*(1), p.e135. https://doi.org/10.1002/est2.135

[32] Kılkış, Ş., Krajačić, G., Duić, N. and Rosen, M.A., (2022). Effective mitigation of climate change with sustainable development of energy, water and environment systems. *Energy conversion and management*, *269*, p.116146. https://doi.org/10.1016/j.enconman.2022.116146

[33] Krähmer, K., (2021). Are green cities sustainable? A degrowth critique of sustainable urban development in Copenhagen. *European Planning Studies*, *29*(7), pp.1272-1289. https://doi.org/10.1080/09654313.2020.1841119

[34] Kumar, G.S., (2023). INNOVATIONS IN BRIDGE DESIGN AND CONSTRUCTION: CABLE-STAYED VS. SUSPENSION BRIDGES. *Journal of Research Administration*, *5*(1), pp.114-124.

[35] Kundu, D. and Pandey, A.K., (2020). World urbanisation: trends and patterns. *Developing national urban policies: Ways forward to green and smart cities*, pp.13-49. https://doi.org/10.1007/978-981-15-3738-7_2

[36] Lamb, Z., Shi, L., Silva, S. and Spicer, J., (2023). Resident-owned resilience: Can cooperative land ownership enable transformative climate adaptation for manufactured housing communities? *Housing Policy Debate*, *33*(5), pp.1055-1077. https://doi.org/10.1080/10511482.2021.2013284

[37] Liang, R.R. and Hota, G.V., (2024). Infrastructure Applications of Fiber-Reinforced Polymer Composites. In *Applied Plastics Engineering Handbook* (pp. 749-781). William Andrew Publishing. https://doi.org/10.1016/B978-0-323-88667-3.00007-2

[38] Mahfoud, R.J., Alkayem, N.F., Zhang, Y., Zheng, Y., Sun, Y. and Alhelou, H.H., (2023). Optimal operation of pumped hydro storage-based energy systems: A compendium of current challenges and future perspectives. *Renewable and Sustainable Energy Reviews*, *178*, p.113267. https://doi.org/10.1016/j.rser.2023.113267

[39] Manfren, M., Nastasi, B., Groppi, D. and Garcia, D.A., (2020). Open data and energy analytics-An analysis of essential information for energy system planning, design and operation. *Energy*, *213*, p.118803. https://doi.org/10.1016/j.energy.2020.118803

[40] Marana, P., Labaka, L. and Sarriegi, J.M., (2020). We need them all: development of a public private people partnership to support a city resilience building process. *Technological Forecasting and Social Change*, *154*, p.119954. https://doi.org/10.1016/j.techfore.2020.119954

[41] Mohammed, M., Shafiq, N., Abdallah, N.A.W., Ayoub, M. and Haruna, A., 2020. A review on achieving sustainable construction waste management through application of 3R (reduction, reuse, recycling): A lifecycle approach. In *IOP Conference Series: Earth and Environmental Science* (Vol. 476, No. 1, p. 012010). IOP Publishing. https://doi.org/10.1088/1755-1315/476/1/012010

[42] Mondal, S. and Palit, D., (2022). Challenges in natural resource management for ecological sustainability. In *Natural Resources Conservation and Advances for Sustainability* (pp. 29-59). Elsevier. https://doi.org/10.1016/B978-0-12-822976-7.00004-1

[43] Moşteanu, N.R., (2020). Green sustainable regional development and digital era. In *Green buildings and renewable energy: Med green forum 2019-part of world renewable energy congress and network* (pp. 181-197). Springer International Publishing. https://doi.org/10.1007/978-3-030-30841-4_13

[44] Muis, S., Apecechea, M.I., Dullaart, J., de Lima Rego, J., Madsen, K.S., Su, J., Yan, K. and Verlaan, M., (2020). A high-resolution global dataset of extreme sea levels, tides, and storm surges, including future projections. *Frontiers in Marine Science*, *7*, p.263. https://doi.org/10.3389/fmars.2020.00263

[45] Murtagh, N., Scott, L. and Fan, J., (2020). Sustainable and resilient construction: Current status and future challenges. *Journal of Cleaner Production*, *268*, p.122264. https://doi.org/10.1016/j.jclepro.2020.122264

[46] Nwokolo, S.C., Eyime, E.E., Obiwulu, A.U. and Ogbulezie, J.C., (2023). Africa's Path to Sustainability: Harnessing Technology, Policy, and Collaboration. *Trends in Renewable Energy*, *10*(1), pp.98-131. https://doi.org/10.17737/tre.2024.10.1.00166

[47] Ogbowuokara, O.S., Leton, T.G., Ugbebor, J.N. and Orikpete, O.F., (2023). Developing climate governance strategies in Nigeria: An emphasis on methane emissions mitigation. The Journal of Engineering and Exact Sciences, 9(9), pp.17383-01e. https://orcid.org/0000-0002-1220-1008

[48] Okafor, E.S., Akinrinola, O., Usman, F.O., Amoo, O.O. and Ochuba, N.A., (2024). Cybersecurity analytics in protecting satellite telecommunications networks: a conceptual development of current trends, challenges, and strategic responses. *International Journal of Applied Research in Social Sciences*, *6*(3), pp.254-266. https://doi.org/10.51594/ijarss.v6i3.854

[49] Olabi, A.G. and Abdelkareem, M.A., (2022). Renewable energy and climate change. *Renewable and Sustainable Energy Reviews*, *158*, p.112111. https://doi.org/10.1016/j.rser.2022.112111

[50] Oladele, I.O., Omotosho, T.F. and Adediran, A.A., 2020. Polymer-based composites: an indispensable material for present and future applications. *International Journal of Polymer Science*, *2020*, pp.1-12.

[51] Ololade, Y.J., (2024). SME FINANCING THROUGH FINTECH: AN ANALYTICAL STUDY OF TRENDS IN NIGERIA AND THE USA. *International Journal of Management & Entrepreneurship Research*, *6*(4), pp.1078-1102.

[52] Omaghomi, T.T., Elufioye, O.A., Ogugua, J.O., Daraojimba, A.I. and Akomolafe, O., (2024). Innovations in hospital management: A review. International Medical Science Research Journal, 4(2), pp.224-234. https://doi.org/10.51594/imsrj.v4i2.820

[53] Orikpete, O.F., Ikemba, S. and Ewim, D.R.E., (2023). Integration of renewable energy technologies in smart building design for enhanced energy efficiency and self-sufficiency. The Journal of Engineering and Exact Sciences, 9(9), pp.16423-01e. https://doi.org/10.18540/jcecvl9iss9pp16423-01e

[54] Orikpete, O.F., Leton, T.G. and Momoh, O.L.Y., (2022). The assessment of perception and effect of helicopter noise in Mgbuoshimini community, Rivers State, Nigeria. Research developments in science and technology, 2, pp.22-52.

[55] Painuly, J.P. and Wohlgemuth, N., (2021). Renewable energy technologies: barriers and policy implications. In *Renewable-energy-driven future* (pp. 539-562). Academic Press. https://doi.org/10.1016/B978-0-12-820539-6.00018-2

[56] Patel, S.K., Ritt, C.L., Deshmukh, A., Wang, Z., Qin, M., Epsztein, R. and Elimelech, M., (2020). The relative insignificance of advanced materials in enhancing the energy efficiency of desalination technologies. *Energy & Environmental Science*, *13*(6), pp.1694-1710. DOI:10.1039/D0EE00341G

[57] Pokhrel, S.R., Chhipi-Shrestha, G., Hewage, K. and Sadiq, R., (2022). Sustainable, resilient, and reliable urban water systems: making the case for a “one water” approach. *Environmental Reviews*, *30*(1), pp.10-29. https://doi.org/10.1139/er-2020-0090

[58] Pozoukidou, G. and Angelidou, M., (2022). Urban planning in the 15-minute city: Revisited under sustainable and smart city developments until 2030. *Smart Cities*, *5*(4), pp.1356-1375. https://doi.org/10.3390/smartcities5040069

[59] Ravish, R. and Swamy, S.R., (2021). Intelligent traffic management: A review of challenges, solutions, and future perspectives. *Transport and Telecommunication Journal*, *22*(2), pp.163-182. https://doi.org/10.2478/ttj-2021-0013

[60] Ruggerio, C.A., (2021). Sustainability and sustainable development: A review of principles and definitions. *Science of the Total Environment*, *786*, p.147481. https://doi.org/10.1016/j.scitotenv.2021.147481

[61] Ryłko-Polak, I., Komala, W. and Białowiec, A., (2022). The reuse of biomass and industrial waste in biocomposite construction materials for decreasing natural resource use and mitigating the environmental impact of the construction industry: a review. *Materials*, *15*(12), p.4078. https://doi.org/10.3390/ma15124078

[62] Sakalasooriya, N., (2021). Conceptual analysis of sustainability and sustainable development. *Open Journal of Social Sciences*, *9*(03), p.396. http://creativecommons.org/licenses/by/4.0/

[63] Saleh, T.A., Fadillah, G. and Ciptawati, E., (2021). Smart advanced responsive materials, synthesis methods and classifications: from Lab to applications. *Journal of Polymer Research*, *28*(6), p.197. https://doi.org/10.1007/s10965-021-02541-x

[64] Salimi, M. and Al-Ghamdi, S.G., (2020). Climate change impacts on critical urban infrastructure and urban resiliency strategies for the Middle East. *Sustainable Cities and Society*, *54*, p.101948. https://doi.org/10.1016/j.scs.2019.101948

[65] Sankaran, V. and Chopra, A., (2020). Creating global sustainable smart cities (a case study of Masdar City). In *Journal of Physics: Conference Series* (Vol. 1706, No. 1, p. 012141). Iop Publishing. https://doi.org/10.1088/1742-6596/1706/1/012141

[66] Schram, T., Sutar, S., Radu, I. and Asselberghs, I., (2022). Challenges of wafer-scale integration of 2D semiconductors for high-performance transistor circuits. *Advanced Materials*, *34*(48), p.2109796. https://doi.org/10.1002/adma.202109796

[67] Sharifi, A., (2021). Co-benefits and synergies between urban climate change mitigation and adaptation measures: A literature review. *Science of the total environment*, *750*, p.141642. https://doi.org/10.1016/j.scitotenv.2020.141642

[68] Sharma, T., Chehri, A. and Fortier, P., (2021). Review of optical and wireless backhaul networks and emerging trends of next generation 5G and 6G technologies. *Transactions on Emerging Telecommunications Technologies*, *32*(3), p.e4155. https://doi.org/10.1002/ett.4155

[69] Shi, C., Guo, N., Gao, X. and Wu, F., (2022). How carbon emission reduction is going to affect urban resilience. *Journal of Cleaner Production*, *372*, p.133737. https://doi.org/10.1016/j.jclepro.2022.133737

[70] Siehr, S.A., Sun, M. and Aranda Nucamendi, J.L., (2022). Blue-green infrastructure for climate resilience and urban multifunctionality in Chinese cities. *Wiley Interdisciplinary Reviews: Energy and Environment*, *11*(5), p.e447. https://doi.org/10.1002/wene.447

[71] Simpeh, E.K., Pillay, J.P.G., Ndihokubwayo, R. and Nalumu, D.J., (2022). Improving energy efficiency of HVAC systems in buildings: A review of best practices. *International Journal of Building Pathology and Adaptation*, *40*(2), pp.165-182. https://doi.org/10.1108/IJBPA-02-2021-0019

[72] Soliman, A., Hafeez, G., Erkmen, E., Ganesan, R., Ouf, M., Hammad, A., Eicker, U. and Moselhi, O., (2022). Innovative construction material technologies for sustainable and resilient civil infrastructure. *Materials Today: Proceedings*, *60*, pp.365-372. https://doi.org/10.1016/j.matpr.2022.01.248

[73] Stamopoulos, D., Dimas, P., Siokas, G. and Siokas, E., (2024). Getting smart or going green? Quantifying the Smart City Industry's economic impact and potential for sustainable growth. *Cities*, *144*, p.104612. https://doi.org/10.1016/j.cities.2023.104612

[74] Stepinac, M., Kisicek, T., Renić, T., Hafner, I. and Bedon, C., (2020). Methods for the assessment of critical properties in existing masonry structures under seismic loads—the ARES project. *Applied Sciences*, *10*(5), p.1576. https://doi.org/10.3390/app10051576

[75] Timilsina, G.R., (2021). Are renewable energy technologies cost competitive for electricity generation? *Renewable Energy*, *180*, pp.658-672. https://doi.org/10.1016/j.renene.2021.08.088

[76] Umana, A.U., Garba, B.M.P., and Audu, A.J. (2024b). Innovations in process optimization for environmental sustainability in emerging markets. International Journal of Multidisciplinary Research Updates, 8(2), pp.49-63. https://doi.org/10.53430/ijmru.2024.8.2.0053.

[77] Umana, A.U., Garba, B.M.P., and Audu, A.J. (2024b). Sustainable business development in resource-intensive industries: Balancing profitability and environmental compliance. International Journal of Multidisciplinary Research Updates, 8(2), pp.64-78. https://doi.org/10.53430/ijmru.2024.8.2.0054.

[78] Umana, A.U., Garba, B.M.P., Ologun, A., Olu, J.S., and Umar, M.O. (2024a). The role of government policies in promoting social housing: A comparative study between Nigeria and other developing nations. World Journal of Advanced Research and Reviews, 23(03), pp.371-382. https://doi.org/10.30574/wjarr.2024.23.3.2699.

[79] Umana, A.U., Garba, B.M.P., Ologun, A., Olu, J.S., and Umar, M.O. (2024b). Architectural design for climate resilience: Adapting buildings to Nigeria's diverse climatic zones. World Journal of Advanced Research and Reviews, 23(03), pp.397-408. https://doi.org/10.30574/wjarr.2024.23.3.2701.

[80] Umana, A.U., Garba, B.M.P., Ologun, A., Olu, J.S., and Umar, M.O. (2024). Innovative design solutions for social housing: Addressing the needs of youth in Urban Nigeria. World Journal of Advanced Research and Reviews, 23(03), pp.383-396. https://doi.org/10.30574/wjarr.2024.23.3.2700.

[81] Umana, A.U., Garba, B.M.P., Ologun, A., Olu, J.S., and Umar, M.O. (2024a). The impact of indigenous architectural practices on modern urban housing in Sub-Saharan Africa. World Journal of Advanced Research and Reviews, 23(03), pp.422-433. https://doi.org/10.30574/wjarr.2024.23.3.2703

[82] Umoh, A.A., Adefemi, A., Ibewe, K.I., Etukudoh, E.A., Ilojianya, V.I. and Nwokediegwu, Z.Q.S., (2024). Green architecture and energy efficiency: a review of innovative design and construction techniques. *Engineering Science & Technology Journal*, *5*(1), pp.185-200. https://doi.org/10.51594/estj.v5i1.743

[83] Verma, A. and Singhania, R., (2023). Urban resilience in the face of climate change: strategies for adaptation and mitigation. *Journal of Sustainable Technologies and Infrastructure Planning*, *7*(1), pp.46-66. https://publications.dlpress.org/index.php/JSTIP/article/view/22

[84] Vogel, E., (2020). A New Electric Transition: Neoliberal Paths for Canadian Hydropower. *Northeastern Geographer*, *12*.

[85] Wheeler, S.M., (2022). Introduction to Part Eight. In *The Sustainable Urban Development Reader* (pp. 434-497). Routledge.