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RESEARCH PAPER

Tracking sustainability compliance of buildings in rapidly urbanizing Southeastern Nigeria

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Abstract. This study examines sustainability compliance in Southeast Nigeria, a region experiencing rapid economic, social, and environmental changes. The research uses a mixed-methods approach to collect both quantitative and qualitative data from various stakeholders, including enterprises, governments agencies, civil society organizations, and local communities. The findings reveal a complex landscape of sustainability compliance, highlighting gaps and barriers such as inadequate regulatory frameworks, limited resource access, and a lack of awareness and capacity-building initiatives. Additionally, cultural and societal factors significantly influence attitudes and behaviours towards sustainability. The study emphasizes the importance of context-specific approaches to sustainability compliance in a region characterized by unique socio-cultural and economic dynamics. It provides recommendations for policymakers, businesses, and civil society organizations to foster greater sustainability awareness, promote responsible practices, and create an enabling environment for sustainable development. Further research and collaborative efforts are needed to address these challenges and advance sustainability objectives in the Southeast region.

Keywords: Sustainability; green building; sustainable construction; environmental impact; energy use efficiency; water use efficiency

1. Introduction

Because of the need for sustainable development, environmental protection, and energy efficiency, green buildings are becoming increasingly important globally. Environmental concerns, economic benefits, health and well-being, and government regulations are among the major drivers of green building adoption (Darko et al., 2018). Green building philosophy is derived from the term "Arcology," which is a combines architecture and ecology (Anshebo et al., 2022). The green building approach focuses on reducing the negative environmental effects of construction and operation while generating healthier and more pleasant living and working environments.

The benefits of energy efficiency include economic development, lower innovation costs, reduced greenhouse gas (GHG) emissions, and the creation of a sustainable energy system (Department of Energy and Climate Change, 2012). Nordhaus (2015) highlights energy efficiency

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as a low-cost solution for reducing GHG emissions. According to Das et al. (2015), one of the fundamental aims of green buildings is to minimize water usage while maintaining water quality. This can be achieved through rooftop rainwater collection, which is stored in tanks or cisterns before being processed and used for non-potable purposes such as landscape irrigation, toilet flushing, and cooling system makeup water (Berardi et al., 2014).

Another key focus of green buildings is the use of sustainable building materials, which reduce environmental impact, boost energy efficiency, and improve overall building sustainability. Barbhuiya & Das (2023) emphasize the need for evaluation of building materials and their impact on sustainability in terms of life cycle cost assessment. Recycled aggregate concrete, for example incorporates recycled aggregates from demolished concrete structures and can exhibit similar mechanical performance to traditional concrete when properly designed and produced (Tam et al., 2018). Numerous studies have shown that waste concrete can be utilized not just as recycled concrete aggregate, but also to replace some of the high-quality limestone required to create cement (Bhagwat et al., 2017).

Beyond cost implications, the nature and type of construction materials used can also affect health conditions. Sick building syndrome is an adverse health condition primarily attributed to building materials and the consequent indoor air quality (IAQ). The indoor environmental quality (IEQ) of buildings is a critical factor influencing occupant health, comfort, and productivity. Measures to improve IAQ can significantly reduce the presence of harmful airborne pollutants in green buildings (Wei et al., 2022). Rawal et al. (2020) emphasized the importance of achieving optimal thermal comfort in green buildings, which utilize innovative techniques like efficient insulation and responsive HVAC systems. Green buildings also prioritize acoustic design, focusing on sound insulation, noise reduction techniques, and material selection to create quiet, comfortable indoor spaces, enhancing occupant satisfaction (Setyowati & Trilistyo, 2016).
Site selection and sustainable land use are critical considerations in green building design and construction. Green design site selection can help maintain the connection between people and nature as well as mitigate against problems related to transportation, urban heat island, excessive energy and water consumption by adopting eco-friendly strategies (Huo et al., 2019).

Smart building automation and controls are critical in green buildings because they improve energy efficiency, increase occupant comfort, and reduce environmental impact. Chasta et al. (2016) suggested a smart building automation system using modern sensors, controls, and radio frequency (RF) modems for real-time monitoring and control of building components, thereby enhancing energy management and optimization. Green building HVAC systems are designed to optimize energy consumption, reduce environmental impact, and improve IAQ through the use of energy-efficient technologies and sustainable practices. The focus is on improving IAQ and thermal comfort by controlling microbial contamination and implementing advanced air filtration technologies, which promote sustainable HVAC systems in green buildings (Asim et al., 2022).

Almost 50% of the energy demand in commercial buildings is used to maintain indoor thermal comfort conditions (Wu, 2015). Dragović et al. (2020) advocated for a shift towards renewable energy sources to combat climate change, reduce fossil fuel reliance, and enhance energy efficiency in green buildings, emphasizing smart energy management and passive design strategies. The integration of renewable energy technologies, like solar panels, wind turbines, geothermal systems, and biomass energy, aims to meet the energy demands of buildings while minimizing environmental impacts and conserving resources.

This study aims to investigate the level of adoption of sustainability principles in building development in Southeast Nigeria. Reports from other parts of the globe indicate that green building practices offer economic benefits, support a sustainable future, address environmental concerns, and create healthier living environments, all of which contribute to a prosperous and environmentally friendly region. According to Ignatius et al. (2022), green buildings can result in cost savings through energy and water efficiency. The Indian Green Building Council (IGBC) reports that green buildings can save 20-30% on water and 40-50% on energy compared to conventional structures. Green Star-certified buildings consume 51% less potable water and emit 62% less GHGs than industry standards. Leadership in Energy and Environmental Design (LEED)-certified green buildings use 11% less water and 25% less energy than non-green structures. Additionally, they reduce construction costs, increase property value, and lead to cost savings on utility bills through energy and water efficiency. Hafez et al. (2023) found that incorporating energy-efficient technologies and practices can lead to reduced energy consumption and lower operational costs over the building's lifespan.

Southeast Nigeria faces challenges in green building due to limited awareness, inadequate policy and regulatory frameworks, and high upfront costs associated with sustainable building strategies. Although the initial investment in green buildings is higher than in traditional buildings, the long-term savings can offset the upfront costs (Sun, 2024).

2. Methodology

2.1. Area of study

This study primarily focuses on buildings in Enugu State, specifically within and around the University of Nigeria, Nsukka, and Enugu Campus, due to accessibility and familiarity with the community.

Figure 1 shows Enugu State in Southeast Nigeria, which features a diverse range of housing types, from traditional huts to modern urban buildings, making it an ideal area to study sustainability compliance in construction. The population is a mix of indigenous Igbo people and migrants engaged in various occupations, including agriculture, trade, government employment, and emerging service and technology industries. The region's varied landscape, spanning fertile plains and hilly terrain, presents unique opportunities and challenges for sustainable building practices in this dynamic Nigerian state.

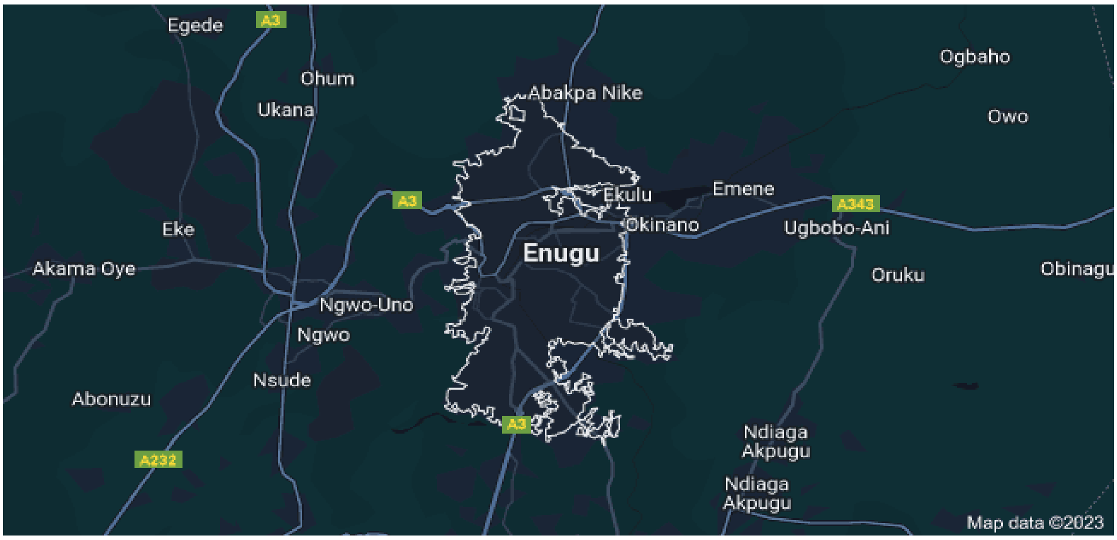

Figure 1. Map of the study area

2.2. Data collection

The instrument used for this study was developed based on the LEED template for green buildings, which prioritizes sustainable design, energy efficiency, and environmental performance. LEED is the world's leading rating system for the design, construction and operation of high-performance green buildings. Over the past 18 years, various versions of LEED have progressively advanced the global green building market, with more than 93,000 registered and certified projects and over 19 billion square feet of space worldwide. It offers a holistic approach that considers various aspects of a building's lifecycle, from construction to operation, ensuring minimal resource consumption and reduced environmental impact. The LEED template's rigorous certification process and global acceptance make it a preferred choice for achieving higher standards of eco-friendliness and long-term sustainability.

For this study, nine sustainability principles were considered, with a total of 110 available credits and fifty-seven specific scorable items (Figure 2). The sustainability principles include integrative process, location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation, and regional priorities. The corresponding credits of these sustainability principles are 1.0, 16, 10, 11, 33, 13, 16, 6.0 and 4.0 respectively (see Table 1).

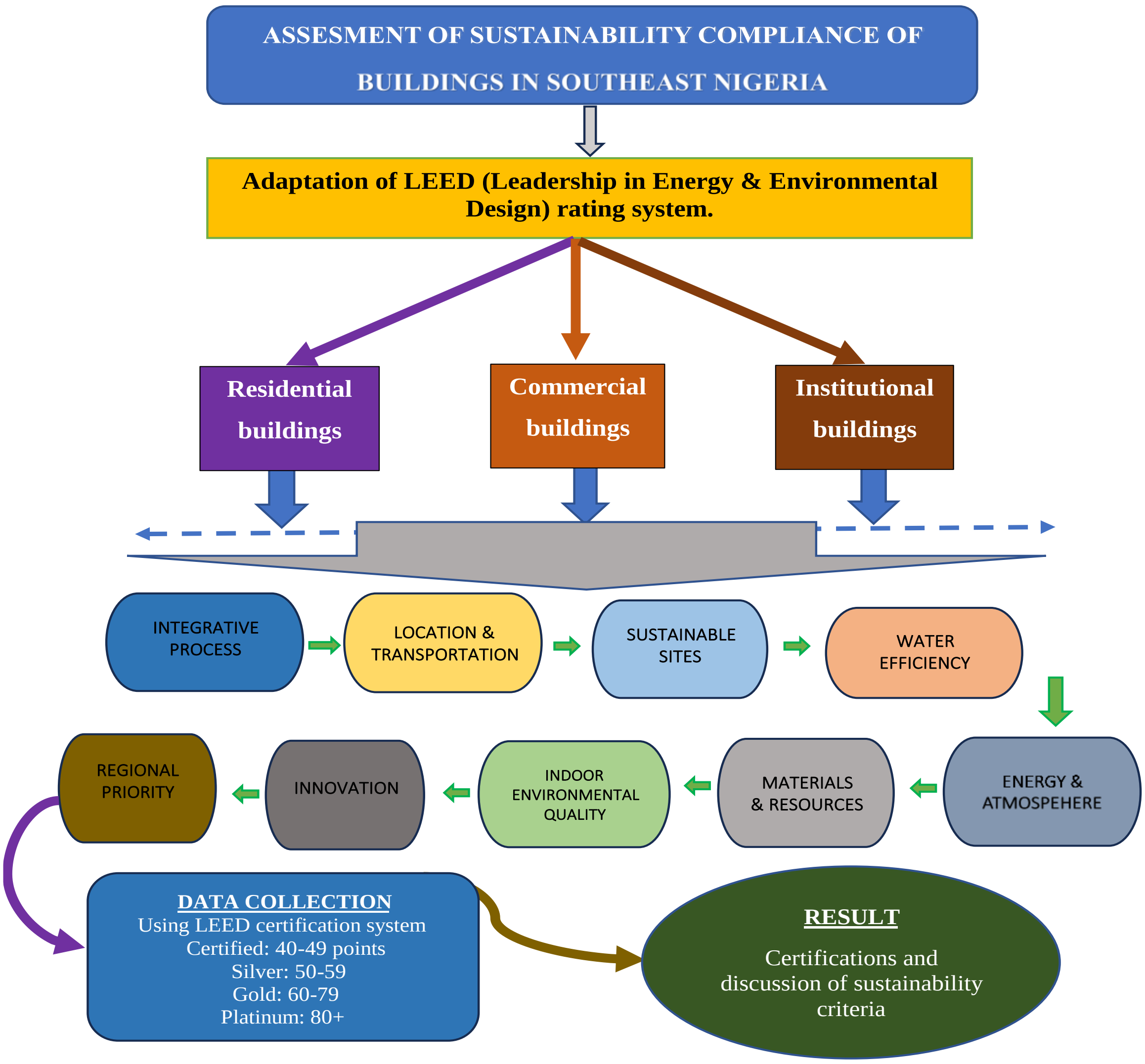

Figure 2. Study design and framework

The questionnaire templates used are designed with three response options: Yes (Y), Not Available (N/A) and No (N). The respondents were required to tick (√) the chosen option in the space provided. The questionnaire templates and observations were used to create the instrument for this study. The study population consisted of commercial buildings, new construction buildings, institutional buildings, and residential buildings. A total of eighty-seven buildings were investigated, categorized as follows: commercial buildings - 13, residential buildings – 43, and institutional buildings – 31 (Table 2).

Table 1. Summary of assessment criteria used in the study

Sustainability principle	Aim	Specific target	Total credit
Integrative Progress (2)	Integrating sustainable practices in both design and occupant satisfaction	Hedonic approval	1.0
Location and Transportation (8)	Minimizing environmental impact, promoting walkability, and encouraging the use of public transit and alternative transportation	Promotion of urban renewal Reduction of urban sprawl preserving greenfield areas	16
Sustainable sites (8)	Assessment of site conditions, environmental justice concerns, and cultural and social factors before design to evaluate sustainable options and inform decisions about site design	• Sustainable design. • Promotion of biodiversity and ecological balance. • Prevention of pollution and strain on local water systems. • Reduction of water consumption • Promotion of sustainable landscaping. • Mitigation of the heat island effect • Improvement in energy efficiency. • Minimizing light pollution and energy waste	10
Efficiency of water (6)	Reduction of outdoor and indoor potable water consumption, preservation of no- and low-cost potable water resources, and identification of opportunities for additional water savings by tracking water consumption.	• Reducing indoor and outdoor water consumption • Minimizing water demand and supporting local ecosystems. • Reducing indoor water consumption. • Tracking of consumption and identifying inefficiencies.	11
Energy and atmosphere (10)	To support energy management and identify opportunities for additional energy savings by tracking building-level energy use, and to further support the design, construction, and eventual operation of a project that meets the owner's requirements for energy, water, indoor environmental quality, and durability.	• Maximizing energy efficiency • Reduction of energy consumption. • Effective indoor comfort • Reducing reliance on fossil fuels. • Optimizing indoor air quality	33
Materials and resources (6)	To encourage adaptive reuse and optimize the environmental performance of products and materials.	• Reducing environmental impact. • informs sustainable choices.	13
Indoor environmental quality (14)	To contribute to the comfort and well-being of all building occupants by establishing minimum standards for IAQ.	• Minimizing indoor emissions • Optimize indoor comfort and air quality. • Reducing energy consumption	16
Innovation (2)	To encourage projects to achieve exceptional or innovative performance that benefit human and environmental health, as well as equity.	• Sustainable advancements • Understanding of sustainability principles	6.0
Regional Priorities (1)	Provide an incentive for achieving credits that address geographically specific environmental, social equity, and public health priorities.	• Addressing unique regional concerns	4.0

Table 2. Summary of buildings investigated

Project type	Frequency	Percentage	Project scope	Frequency	Percentage
Commercial	13	14	Existing building operations	54	61.6
Institutional	31	36	Maintenance	0	0
Residential	43	50	New Construction	25	29.1
Total	87	100	Renovation	8	9.3
			Total	87	100

In carrying out this study, ethical procedures were observed. These includes attaching a letter that introduced the respondents to the researcher and detailed the purpose of the research. The letter also assured the respondents that they were not under any obligation to participate and included a consent form to be signed. Furthermore, the respondents were assured that their personal information would remain confidential and that the results of the data analysis could be provided to them upon request.

3. Result and discussion

Table 3 provides a summary of the sustainability ratings of the various categories of buildings investigated. Based on the LEEDS certification system, a total of fifty-three buildings (61%) were certified, while thirty-four buildings (39%) failed to achieve sustainability certification. Of the buildings that passed certification, 14 (26%) meet the minimum certification requirements, 12 (22.6%) were rated as "silver", 20 (37.7%) were rated as "gold", and 7 (13.2%) were rated as "platinum". Among the building categories, institutional buildings demonstrated the highest compliance with sustainability concepts, with 77% passing certification, followed by residential buildings at 53%. Commercial buildings showed the least sustainability compliance, with more than half (54%) failing certification. The disparity and unsatisfactory level of compliance with sustainability values in the study area can be attributed to a lack of awareness of sustainability measures and deliberate violations of building codes (Atamewan, 2019).

Table 3. Summary of sustainability rating of buildings in the study area

Ratings	Residential		Institutional		Commercial		Total by Rating
	Count	Percentage	Count	Percentage	Count	Percentage	
Not Certified	20	47%	7	23%	7	54%	34
Certified	9	21%	3	10%	2	15%	14
Silver	3	7%	8	26%	1	8%	12
Gold	9	21%	10	32%	1	8%	20

3.1. Energi and atmosphere

Specification of energy-efficient appliances and equipment ranked highest among all the points considered under the "Energy and atmosphere" section, with a percentage of "yes' responses of 74.2%, 66.7%, and 61.3% for residential, commercial, and institutional buildings, respectively (Table 4). However, it is important to note that the widespread adoption of energy-saving appliances is driven by factors other than core sustainability principles. Factors such as income, education, area of residence, and attitudes toward energy efficiency significantly influenced individuals' willingness to pay (WTP) for these appliances (Harajli & Chalak, 2020). The gravitation towards these appliances in Nigeria has generally been motivated by the quest to reduce the heavy burden of electricity tariffs. In the past, when the power distribution business was government-controlled and electricity consumption was poorly metered, most people were less concerned about energy-saving appliances. The shift became imperative after the privatization of the Power Holding Company of Nigeria (PHCN) and the introduction of more rigorous metering by distribution companies.

Table 4. Energy and atmosphere

	Sustainability issues	Available credit	Mean credit	%Yes	Rank	Mean credit	%Yes	Rank	Mean credit	%Yes	Rank	Aggregate rank
			Residential			Commercial			Institutional			
1	Enhanced commissioning of project to ensure proper installation?	3	0.49	16.28	7	1.00	33.33	2	1.35	45.16	4	4
2	Addressing verification of energy-related systems?	3	0.91	30.23	4	0.75	25.00	3	1.16	38.71	5	5
3	Specification of energy-efficient appliances and equipment?	6	4.47	74.42	1	4.00	66.67	1	3.68	61.29	1	1
4	Regular energy performance monitoring for measurement?	6	1.12	18.60	3	0.00	0.00	10	1.94	32.26	3	3
5	Design of insulation and building strategies?	6	1.95	32.56	2	0.50	8.33	4	3.29	54.84	2	2
6	Incorporating advanced energy metering systems?	1	0.30	30.23	9	0.083	8.33	9	0.19	19.35	9	9
7	Utilizing smart grid technology?	2	0.32	16.30	8	0.17	8.33	7	0.065	3.23	10	9
8	Incorporating renewable energy sources?	2.5	0.51	25.58	6	0.33	16.67	6	0.71	35.48	7	7
9	Ensuring proper installation sizing and design of renewable energy systems?	2.5	0.77	25.58	5	0.50	16.67	4	1.06	35.48	6	6
10	Implementation of criteria to evaluate the compliance of HVAC systems?	1	0.16	16.28	10	0.17	16.67	7	0.45	45.16	8	8

Incorporating advanced energy metering systems and utilizing smart grid technology ranked lowest in the Energy and Atmosphere section. This is attributed to limited awareness and investment in modern energy infrastructure, as well as a preference for addressing more immediate energy access and reliability issues in the region. Additionally, potential regulatory and financial barriers might hinder the widespread adoption of these advanced technologies. Olajuyigbe et al. (2012) point out that limited awareness and inadequate investment in modern energy infrastructure in Nigeria have resulted in maintenance deficiencies, coordination problems, and insufficient generation capacity.

Solar panels and LED bulbs are an effective duo for energy conservation. The aggressive penetration of LED bulbs into the Nigerian market within the past few years can only be attributed to its high energy efficiency, thus drastically cutting electricity consumption. Solar panels harness sunlight to generate clean electricity, reducing reliance on non-renewable energy sources. LED bulbs, on the other hand, consume minimal energy and have a longer lifespan, making them an eco-friendly and cost-effective lighting choice that complements solar power to create a sustainable and energy-efficient solution for homes and businesses. Maka and Alabid (2022) highlighted the significant role of solar power in sustainable building, stabilizing energy prices, and offering numerous social, environmental, and economic benefits. Despite global efforts to reduce carbon emissions, it has been reported that the negative impact of carbon emissions on the atmosphere has been increasing over the past decade (Maka & Alabid, 2022). With nearly 7 billion people living in developing countries, the cumulative effect of reliance on various fossil fuels portends a danger to the climate and the already fragile bio-physical environment. Unfortunately, the incorporation of renewable energy (RE) sources ranked very low in the study area, which can be attributed to two major factors: the high initial high capital demand for modular solar installations, often beyond the reach of the average citizen, and the low level of awareness among the general population, meaning even those who can afford the high initial investment may not see the need to do so. Abdullahi et al. (2017) identified barriers to the incorporation of RE sources in Nigeria, including technical challenges, lack of consumer awareness, economic and financial constraints, institutional and legal barriers, political issues, and market distortions.

However, the recent global increase in the manufacturing of micro and modular solar rechargeable household appliances, mostly for nighttime lighting, has been a source of relief for many low- and middle-income earners, who are typically the direct recipients of the impact of an unreliable power supply in developing countries. Research has shown that Nigeria's annual solar energy potential, at 5% conversion efficiency, is about 15×10^{14} kJ, which is equivalent to 285.62 million barrels of crude oil and 26 times the country's current annual electricity generation (Oyedepo, 2012). The combination of LED bulbs and modular solar power systems has become as a panacea for the epileptic electricity situation in Southeastern Nigeria (Figure 3 & 4). This also means that solar batteries can now last much longer and can handle more electrical appliances than in the past when a few filament bulbs would have placed a high energy demand.

Figure 3. Solar powered-electric car charging station at the University of Nigeria, Nsukka Campus

Figure 4. Common energy-devices in study area

3.2. Sustainable sites

The provisions for passive recreational activities within the open space ranked first, with a percentage of "yes" responses being 51.2%, 50%, and 83.9% for the residential, commercial and institutional buildings, respectively (Table 5). This was followed by the importance of minimizing the impact of rainwater runoff on nearby water bodies or sewer systems. The emphasis on passive recreational activities in open spaces in Southeast Nigeria can be attributed to the region's heavy rainfall, which poses both flooding risks and opportunities for agriculture. Efforts have been made to prevent flooding and promote agriculture by providing amenities such as benches and greenery in these spaces, addressing the leisure and relaxation needs of residents. Additionally, it is notable that residents have a preference for building houses amidst the trees, showcasing their affinity for natural surroundings. Open spaces can offer opportunities for passive recreational activities, such as relaxation and social interaction (Simon, 2015).

The incorporation of water-efficient irrigation systems, such as drip irrigation or smart controllers, to minimize water consumption ranked last in the sustainable sites section, with a percentage of "yes" responses being 13.95%, 33.33%, and 32.26% for residential, commercial, and institutional buildings, respectively. This low ranking is due to the lack of awareness and access to water-efficient irrigation technologies, coupled with limited resources and infrastructure support. Adelodun and Choi (2018) pointed out that the lack of awareness and access to water-efficient irrigation technologies in Nigeria is a significant challenge hindering the development of irrigation systems in the country.

Incorporation of rainwater harvesting systems ranked high for residential and commercial buildings but ranked low for institutional buildings. This is because institutional buildings, which are largely government-owned are usually given preference concerning connection and access to municipal water supplies. Besides, they often have enough resources to provide alternative water supply in the absence of municipal supply. Consequently, the majority of citizens who are not connected to the municipal supply resort to various self-help methods of water supply. This underscores the crucial role of rainwater harvesting in filling the gap created by the failure of municipal water supply systems in the study area.

Kabo-Bah et al. (2021) observed that the water crisis triggered in Africa by a rapidly growing population can be ameliorated by rainwater harvesting, thus saving women and children an enormous amount of energy. Besides the associated stress, there is also a heavy cost burden asso-

Table 5. Sustainable Site

S/N	Sustainability Issues	Available Credit	Mean Credit	%Yes	Rank	Mean Credit	%Yes	Rank	Mean Credit	%Yes	Rank	Aggregate Rank
			Residential			Commercial			Institutional			
1	Conducting assessment to evaluate the environmental impact and potential opportunities of the project site.	1	0.26	25.58	7	0.00	0.00	8	0.55	54.84	4	6
2	Assessing the potential for creating wildlife corridors or connecting habitats.	2	0.33	16.28	6	0.36	18.18	5	0.52	25.80	5	5
3	Provisions for passive recreational activities within the open space.	1	0.51	51.16	1	0.50	50.00	1	0.84	83.87	1	1
4	Minimizing the impact of rainwater runoff on nearby water bodies or sewer systems.	1	0.47	45.51	2	0.50	50.00	1	0.61	61.29	3	2
5	Incorporation of rainwater harvesting systems to capture and store rainwater for on-site use.	1	0.37	37.21	3	0.50	50.00	1	0.45	45.16	6	4
6	Incorporation of water-efficient irrigation systems, such as drip irrigation or smart controllers, to minimize water consumption.	1	0.14	13.95	8	0.33	33.33	7	0.32	32.26	7	8
7	Addressing the potential for incorporating green roofs or rooftop gardens to mitigate the heat island effect.	2	0.37	18.60	3	0.36	18.18	5	0.19	9.68	8	7
8	Considering the potential for utilizing directional lighting to minimize upward light projection.	1	0.37	37.21	3	0.42	41.67	4	0.71	70.97	2	3

cited with the lack of access to municipal supplies. The minimal involvement of the government in water supply has facilitated the takeover of the water supply by middle-water merchantmen, known as water vendors. These vendors typically use their trucks to obtain water and supply it to households at prices solely decided by the them. This group of merchantmen has become the main water supply hub in many cities (Nnaji & Banigo, 2018) and controls the water supply to over 90% of residents in some urban clusters (Olajuyigbe & Rotowa, 2012). Under these circumstances, the role of rainwater harvesting as a major source of water supply assumes a critical dimension.

Nnaji et al. (2017) reported that rainwater has the potential to meet between 29% and 100% of domestic water needs, depending on consumption level, size of rooftop area per capita of the occupant, and available storage. However, rainwater harvesting has faced a significant level of both apathy and skepticism due to concerns about its quality. Other limiting considerations include constraints on storage requirements for prolonged supply during the dry season, the cost of installation, and variabilities in both spatial and seasonal distribution of rainfall.

Abuseif et al. (2022) emphasized the importance of trees in sustainable buildings as a means to mitigate climate change, improve microclimates, and enhance overall environmental quality. Trees on buildings were considered a valuable component of green infrastructure, with significant potential to contribute to sustainability goals (see Figure 5).

Figure 5. Cultivation of trees for sustainable sites

3.3. Indoor air quality

Strategies to enhance IAQ rank at the top, with a percentage of "yes" responses being of 60.47%, 58.33%, and 87.10% for residential, commercial and institutional buildings, respectively (Table 6). This is followed by strategies to maximize access to natural views from occupied spaces. Southeast Nigerian residents and institutions are prioritizing window size and placement to improve IAQ, recognizing the importance of natural ventilation. Okello et al. (2023) noted that the rate of air pollution in Africa has been aggravated by aggressive urbanization, which in turn necessitates higher energy demands for industries, transportation, and domestic purposes. The significance of IAQ has grown dramatically during the COVID-19 pandemic and even in the post-COVID era, as more people now spend more time indoors than in the recent past (Prabhakaran et al., 2022).

According to a survey by the US Bureau of Labour Statistics, about 38% of employed persons did some or all of their work at home on workdays for an average of 5.6 hours (Silver, 2023). This further implies that the health of a significant proportion of society will increasingly depend on IAQ. Nnaji et al. (2023) observed that the continuous generation of indoor pollutants, coupled with poor spatial dispersion, can cause a gradual buildup of dangerous gaseous and particulate matters, leading to death or permanent disabilities. More specifically, Nair et al. (2022) noted that indoor

Table 6. Indoor Air Quality (IAQ)

S/N	Sustainability Issues	Available Credit	Mean Credit	%Yes	Rank	Mean Credit	%Yes	Rank	Mean Credit	%Yes	Rank	Aggregate Rank
			Residential			Commercial			Institutional			
1	Strategies to enhance indoor air quality	2	1.21	60.47	1	1.17	58.33	1	1.74	87.10	1	1
2	Site's potential for using low-emitting materials for doors, frames, and hardware.	1.5	0.42	41.86	10	0.50	50.00	5	0.71	70.97	9	9
3	Use of adhesives that comply with the low VOC content standards.	1.5	0.79	39.53	2	0.67	33.33	3	1.03	51.1	2	3
4	Management plans to address the mitigation of IAQ concerns during the construction phase	1	0.42	20.93	10	0.17	8.33	14	0.45	22.58	12	12
5	Installation of HVAC systems	2	0.44	43.83	9	0.50	50.00	5	0.87	87.10	6	8
6	Measures to address potential thermal discomfort caused by direct sunlight, glare, or radiant heat gain.	1	0.67	67.44	3	0.50	50.00	5	0.87	87.10	6	6
7	Energy-efficient lighting technologies	1	0.67	67.44	3	0.83	83.33	2	0.90	90.32	3	4
8	Strategies to minimize the accumulation of dust, allergens, or other contaminants on lighting fixtures and components.	1	0.42	41.86	10	0.33	33.33	11	0.52	51.61	11	11
9	Prioritizing the incorporation of daylight to enhance indoor air quality.	1	0.65	65.11	5	0.58	58.33	4	0.84	83.87	8	5
10	Use of materials and finishes that optimize the reflection and diffusion of daylight, improving indoor air quality and visual comfort.	1	0.53	53.49	7	0.50	50.00	5	0.90	90.32	3	7
11	Strategies to educate building occupants about the benefits of natural daylight and its positive impact on IAQ and overall well-being.	1	0.37	37.21	13	0.33	33.33	11	0.42	41.94	13	13
12	Strategies to maximize access to natural views from occupied spaces.	0.5	0.37	37.21	13	0.33	33.33	11	0.42	41.94	13	2
13	Incorporating outdoor gathering spaces and green areas that are visible from indoor spaces, promoting a connection to nature and enhancing IAQ	0.5	0.60	60.47	6	0.50	50.00	5	0.90	90.32	3	10
14	Measures to ensure that building materials and finishes selected for acoustic purposes do not compromise IAQ	1	0.49	48.83	8	0.42	41.67	10	0.58	58.06	10	14

environmental parameters such as temperature and humidity have a considerable influence on virus transmission. Hence, sustainable building design and construction must account for these factors and provide measures for mitigation. Nair et al. (2022) identified three broad categories of IAQ control strategies: source control, ventilation, and purification/filtration. Features like air vents and large windows promote better airflow and healthier environments. Okanya et al. (2021) pointed out that strategies to enhance IAQ in Nigeria may involve increasing ventilation rates with outdoor air and minimizing or controlling sources of air pollution both within and outside buildings. Ventilation has been identified as an efficient engineering strategy that improves indoor quality through the dilution and dispersion of pollutants (Nembhard et al., 2020). While natural ventilation, facilitated by the movement of air through doors and windows, can significantly improve IAQ, its efficiency depends largely on the availability of favorable environmental conditions (Nembhard et al., 2020).

Better control and improvement of IAQ can be achieved through the use of mechanical heating, ventilation, and air-conditioning (HVAC) systems. However, the application of HVAC systems in the study location has largely been impaired by an epileptic power supply as well as the relatively high electricity tariffs, which makes such devices an exclusive luxury for middle- and high-income earners, thriving businesses, and government-owned establishments. This is further confirmed by results in Table 5, showing that the order of performance in terms of HVAC installation in buildings is as follows: institutional buildings with 87% positive responses, commercial buildings with 50% positive responses, and residential buildings with 44% positive responses.

Further analysis of Table 6 reveals that buildings in the study area generally performed poorly in HVAC installations compared to other IAQ indices with ranks of 9/13, 5/13 and 8/13 for residential, commercial and institutional buildings respectively. Also, in Southeast Nigeria, a significant gap exists in the absence of a comprehensive management plan dedicated to addressing the mitigation of indoor air quality (IAQ) concerns specifically during the construction phase of building projects as this rank twelfth in the indoor air quality section.

Nardocci et al. (2023) emphasize the increasing concern over IAQ, especially its impact on vulnerable populations such as children, pregnant women, and the elderly. To curb this in southeast Nigeria, especially due to the hot and humid climate, proper window size and strategically placed air vents are recommended (Figure 6). Window size and air vent placement enhance natural ventilation, reducing indoor air pollutants and maintaining comfortable temperatures, while well-placed air vents promote a healthier indoor environment.

Figure 6. Strategies for improving indoor air quality in the study area

3.4. Water efficiency

The installation of water-efficient fixtures and fittings is a historical traditional practice in Southeast Nigeria. Water conservation measures and the reduction of potable water consumption for outdoor uses ranked topmost for water efficiency in the study area (Table 7). This is because the people of Southeast Nigeria use water harvesters and reservoirs to reduce the cost of buying potable water. Most buildings in Southeast Nigeria do not utilize water meters, missing out on their vital role in measuring consumption, promoting water conservation, and detecting leaks. The limited adoption of water meters in the region is likely due to factors such as infrastructure

Table 7. Water efficiency

S/N	Sustainability Issues	Available Credit	Residential Mean Credit	Residential %Yes	Residential Rank	Commercial Mean Credit	Commercial %Yes	Commercial Rank	Institutional Mean Credit	Institutional %Yes	Institutional Rank	Aggregate Score
1	Reduction of potable water consumption for outdoor uses	1	0.37	37.21	3	0.33	33.33	4	0.61	61.29	3	3
2	Water-efficient landscaping and irrigation systems	1	0.37	37.21	3	0.33	33.33	4	0.55	54.84	5	5
3	Reduction of potable water consumption for indoor uses	3	0.63	20.93	5	0.50	16.67	3	0.58	19.35	4	4
4	Installation of water-efficient fixtures and fittings	3	2.09	69.77	1	1.50	50.00	1	2.13	70.97	1	1
5	Water conservation measures	2	1.30	65.12	2	1.00	50.00	2	1.29	64.52	2	2
6	Installation of water metres	1	0.18	20.93	5	0.00	0.00	6	0.13	12.90	6	6

Table 8. Material and resources

S/N	Sustainability Issues	Available Credit	Residential Mean Credit	Residential %Yes	Residential Rank	Commercial Mean Credit	Commercial %Yes	Commercial Rank	Institutional Mean Credit	Institutional %Yes	Institutional Rank	Aggregate Score
1	Reduction of the embodied carbon and environmental footprint of the project	2	0.74	37.21	2	0.50	25.00	2	1.16	58.06	2	2
2	Evaluating the environmental impacts of building materials	3	0.49	16.28	4	0.25	8.33	3	0.77	25.80	4	3
3	Declarations of environmental products (EPDs) obtained for building materials used in the project	2	0.37	18.60	3	0.33	16.67	4	0.65	19.35	5	4
4	Sourcing of materials from manufacturers with environmental product declarations or other sustainability certifications	2	0.33	16.28	4	0.17	8.34	6	0.64	32.25	3	5
5	Requesting information on the chemical ingredients of building products from manufacturers	2	0.34	16.29	5	0.18	8.35	5	0.00	0.00	6	6
6	Minimizing construction waste and diverting it from landfills through recycling and reuse	2	1.12	55.82	1	0.67	33.35	1	1.68	83.85	1	1

constraints, financial challenges, and regulatory issues that hinder their widespread implementation. Intelligent water metering technology can provide valuable data and information for managing water consumption patterns and meeting supply objectives. However, several challenges are associated with its adoption, including cost, customer benefits, privacy, and technical capacity (Boyle et al., 2013).

Some houses in Southeast Nigeria employ rainwater harvesters to support sustainable building practices, like irrigation, construction, and sanitation (Figure 7). Southern Nigeria experiences eight months of rainfall annually, with an average of 1,800-2,250 mm, and the rainy season spans from March to April and November to March (Lade et al., 2013). Christian and Izuchukwu (2009) observed a recent decline in rainfall in the Enugu metropolis, with notable inter-annual variability and a dip in August rainfall. Ripiye and Abenu (2023) emphasized the significance of reducing potable water consumption for outdoor uses in domestic water conservation efforts by implementing measures such as rainwater harvesting and greywater reuse.

Figure 7. Implementation of water efficiency

According to Ogunjimi and Adekalu (2002b), most farmers are illiterate and lack knowledge of water requirements, irrigation scheduling, and pump maintenance, which results in over- or under-irrigation of crops and water wastage. Irrigation systems optimize water application, increase efficiency, and reduce costs in agricultural production by considering factors like crop type, soil conditions, topography, and water quality. Well-designed technologies like automation, real-time scheduling, and precision farming practices enhance these benefits (Holzapfel et al., 2009).

Water meters are devices installed at the entry point of a property to measure and quantify the volume of water consumption, facilitating accurate billing and efficient water resource management. In Southeast Nigeria, the reluctance to embrace water meters is rooted in a combination of cultural factors and scepticism towards the effectiveness of metering systems. Many individuals in the region may view water as a communal resource, and the introduction of meters might be perceived as a departure from traditional communal practices, fostering resistance to their adoption. Rodriguez (2005) emphasizes water as a valuable resource and underscores the importance of water meter precision for effective management, conservation, and equitable distribution, especially in urban areas with growing demands and limited resources. The evolution of water meters, from ancient measuring devices to modern technology, reflects the ongoing efforts to accurately quantify and manage this essential resource.

Boreholes also provide reliable access to groundwater, reducing strain on surface water and contributing to environmentally responsible building practices in the region. Okhuebor and Izevbuwa (2020) highlighted the importance of borehole water in Benin City, Nigeria, as a quick, cost-effective, and essential resource for daily living due to the region's water delivery infrastructure breakdown.

3.5. Materials and resources

Minimizing construction waste and diverting it from landfills through recycling and reuse ranks first with a percentage of "yes" response of 55.82%, 33.35%, and 83.85% for the residential, commercial, and institutional buildings, respectively (Table 8). This is because for a building to be livable, it must be rid of construction waste. Construction waste primarily results from demolition and renovation and has significant negative effects, including environmental hazards, the loss of valuable land, increased costs, and unsightly surroundings (Koleoso et al., 2008). Baitule et al. (2020) pointed out that construction waste is a significant problem, leading to economic, environmental, and societal challenges that require urgent attention and improved management practices.

Airaksinen and Matilainen (2011) emphasize that as measures to improve energy efficiency in buildings, such as improved insulation and reduced air leakage, are implemented, they result in increased material use. This heightened material use becomes a crucial factor influencing the environmental footprint, particularly in terms of embodied carbon and overall life cycle energy consumption in the building sector. Some of these materials, which pose a threat to environmental footprint, include concrete, aluminum, steel, bricks, adhesives and sealants. Ondová et al. (2020) opine that the embodied carbon and environmental footprint of a project, specifically in the context of concrete slab foundations, can be reduced by changing materials and implementing sustainable building technologies, such as using non-conventional materials like rammed earth tire foundations.

People in Southeast Nigeria exhibit a commendable effort in addressing environmental impacts associated with building materials, employing sustainable practices and initiatives to mitigate ecological concerns. They do this by curtailing deforestation and using alternative building materials like bamboo and wood. Atanda (2015) emphasizes that bamboo serves as a substitute material for construction purposes in Nigeria, with potential applications such as substituting steel reinforcement in concrete. The importance lies in bamboo's strength, flexibility, and environmental advantages, making it a viable and sustainable alternative to traditional construction materials. Ekhaese and Ndimako (2023) highlight the benefits of eco-friendly building materials, including healthier indoor spaces, disease prevention, cost reduction, and mitigating global GHG emissions.

In southeast Nigeria, there is poor practice by both engineers and occupants in regards to the declarations of environmental products, as most do not see the need to know the environmental implications of materials used in construction. According to Del Rosario et al. (2021), Environmental Product Declarations (EPDs) are considered advantageous for conducting Life-Cycle Assessment (LCA) within Green Building Rating Systems (GBRSs), as they can help avoid overestimation of environmental impacts and contribute to more accurate sustainability evaluations.

Requesting information on the chemical ingredients of building products from manufacturers ranked last percentage of "yes" response of 16.29%, 8.35%, and 0.00% for residential, commercial, and institutional buildings, respectively. This is attributed to limited awareness of the potential health and environmental impacts of these ingredients among survey participants or a perceived lack of urgency in compared to other sustainability aspects in Southeast Nigeria's building practices.

The study reveals a shift towards sustainable construction practices in Southeast Nigeria, incorporating eco-friendly materials, energy-efficient designs, and waste reduction strategies in some projects. However, regressive trends in the construction sector highlight challenges due to economic constraints, inconsistent regulations, and limited access to sustainable technologies, potentially hindering sustainability goals and contributing to environmental degradation. This result do not correspond with the study of Aghimien et al. (2019), who noted that there has been an increase in awareness and usage of sustainable construction (SC) materials in Nigeria compared to earlier studies conducted in 2012 and 2017. Therefore, to address this divergence, it's vital to promote education and awareness of sustainable building practices, incentivize green building initiatives, and strengthen regulatory frameworks. A holistic approach that considers economic, social, and environmental aspects is essential for steering Nigeria's construction sector towards a more sustainable and resilient future.

The study on sustainability compliance of buildings in Southeast Nigeria reveals that there is a need for more work in the construction sector (Figure 8). The average LEED rating system compliance is 48 points, but poor compliance is attributed to limited awareness, resource constraints, and a focus on short-term economic gains. Alhassan et al. (2022) identified several challenges related to sustainable buildings in Nigeria, including a lack of awareness among stakeholders and the perception of high costs associated with green building features.

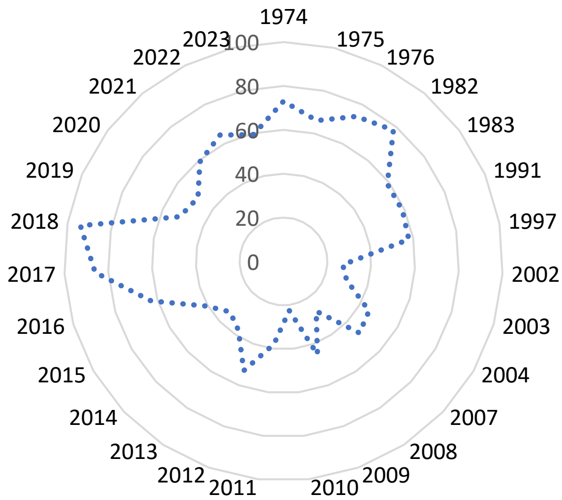

Figure 8. Trends of sustainability compliance over the years

Our analysis reveals a significant opportunity to improve sustainable building practices in Southeast Nigeria, with current compliance rates of 30%. The goal is to achieve a 70% compliance rate in Southeast Nigeria by 2040, utilizing strategic methodologies and unwavering commitment. This ambitious vision aims to reshape sustainable construction, benefiting the environment and ensuring a brighter future for generation.

4. Conclusion and recommendations

The sustainability compliance project in Southeast Nigeria is crucial for the region's future, ensuring responsible urban development and environmental stewardship (Figure 9). By incorporating unique climate, materials, and cultural context, sustainable practices are feasible and beneficial. The initiative emphasizes strengthening and enforcing green building regulations through collaborating partnerships with local governments, offering incentives and penalties for non-compliance. Green building certification programs like LEED and BREEAM promote excellence, compliance, and environmental responsibility, elevating construction standards by encouraging developers to pursue these certifications.

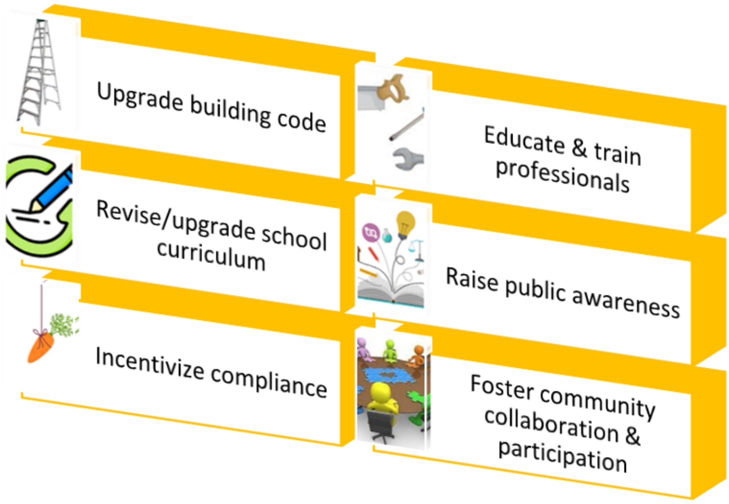

Figure 9. Flowchart showing the future state of sustainability in southeast Nigeria

Public awareness campaigns about green buildings' benefits, such as energy efficiency and reduced environmental impact, foster demand for eco-friendly structures and drive developers towards greener practices. Independent audits are crucial for ensuring ongoing compliance with green building standards and providing transparency and accountability through regular assessments. Southeast Nigeria can foster a thriving green building industry by investing in research and innovation in locally sourced, eco-friendly building materials and technologies.

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