

Role of Transforming Informal Settlements into Green Buildings in Developing Countries

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How to cite this paper: Nkurikiye, E., & Ma, X. (2025). Role of Transforming Informal Settlements into Green Buildings in Developing Countries. *Current Urban Studies*, 13, 71-98.

<https://doi.org/10.4236/cus.2025.132004>

Received: April 25, 2025

Accepted: May 18, 2025

Published: May 21, 2025

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Abstract

Informal settlements in developing countries present complex challenges that demand a shift from conventional upgrading strategies. Existing research highlights growing disparities between developed and developing nations and between planned and unplanned urban areas, underscoring the urgency for sustainable solutions. Green building principles centered on ecologically responsible design, construction, and resource efficiency offer transformative potential for these settlements. However, current frameworks often neglect socio-economic, cultural, and technological integration, limiting their scalability. Additionally, minimal research explores how informal construction practices can align with green technologies to enhance affordability and community acceptance. This study examines the role of green building principles in upgrading informal settlements, assessing both opportunities and barriers. By focusing on energy-efficient retrofitting, sustainable materials, and community-driven initiatives, it assesses policy reforms, flexible building codes, and technological innovations through case studies such as Brazil, Ethiopia, and South Africa. Findings reveal a critical gap in holistic strategies and propose scalable, cost-effective solutions such as modular designs, localized material sourcing, and participatory engagement models to ensure inclusive housing for low-income populations. The transition to green buildings, though complex, is essential for sustainable urbanization. Success requires a multidisciplinary approach combining policy adjustments (e.g., subsidies for green retrofitting), technical advancements (e.g., decentralized solar systems), and active community involvement to address financial, governance, and social barriers. As cities in developing regions expand, prioritizing green construction in informal settlements is vital to fostering resilient, equitable, and ecologically sustainable urban environments. This study advances discourse by identifying key challenges, such as high upfront costs and fragmented governance, and opportunities, including job creation and long-term energy savings. It also highlights research gaps, such as the need for climate-resilient designs and digital tools

for participatory planning. By providing actionable insights, the paper equips policymakers, researchers, and practitioners with strategies to develop context-sensitive, scalable green solutions for vulnerable urban populations. Ultimately, proactive investment in these approaches can mitigate urban poverty, reduce carbon footprints, and promote inclusive growth in rapidly urbanizing regions.

Keywords

Informal Settlements, Green Building, Sustainable Urban, Energy-Efficient, Community-Driven

1. Introduction

Throughout history, governmental bodies have implemented a variety of slum upgrading projects and programs with varying scales and scopes. However, despite the accumulation of experience and knowledge in this field, the proliferation of slums and informal settlements continues to grow, particularly in regions such as Asia, Sub-Saharan Africa, and Latin America (UN-Habitat, 2020; Ndinda et al., 2021). Urbanization in developing countries has led to the rapid expansion of informal settlements, where millions of people reside in substandard living conditions characterized by inadequate infrastructure, poor sanitation, and lack of access to essential services (Sato, 2024). The rapid growth of informal settlements in recent years highlights the critical importance of studying inequalities in informal settlements (Cinnamon and Noth, 2023). Today, 1 billion of the world's urban population live in informal settlements (UN-Habitat, 2020). In Ethiopia, the study on the transformation of informal settlements revealed a significant increase on the city's outskirts, expanding from 77 ha in 2009 (2% of the total area) to 765.6 ha in 2023 (21% of the total area) (Gedefaw et al., 2020). Referring to this example of the study made in Addis Ababa, they evaluated the monetary value of the loss in ecosystem services due to the expansion of informal settlements and explored strategies to mitigate these adverse effects through sustainable urban planning and land management practices. The specific objectives of the study are (i) land use land cover changes in 2009, 2011, and 2023, (ii) informal settlements from 2009 to 2023, and (iii) ecosystem services from 2009 to 2023.

The existing studies show that the several spatial and social inequalities in informal settlements as discussed in this document, including lack of access to infrastructure, economic informality, gender inequality, and urban violence (UN-Habitat, 2020). Therefore, the transformation of informal settlements into green buildings is highly needed. Additionally, these settlements, often developed without formal planning, contribute significantly to environmental degradation due to inefficient energy consumption, improper waste disposal, and unsustainable construction practices (Sharma et al., 2025; UN-Habitat, 2020). As the global focus shifts towards sustainable urban development, transforming informal settle-

ments into green buildings presents a viable solution that aligns with environmental, social, and economic sustainability goals (Hafez et al., 2023; Loor et al., 2021). Countries such as the United States (U.S.), Canada, and Europe are at the forefront of the global adoption of green building practices; cities such as Singapore City, Hong Kong, and Tokyo also advocate for the implementation of green building practices.

Green buildings, characterized by energy efficiency, resource conservation, and eco-friendly design, provide a viable strategy to transform informal settlements while countering the adverse effects of rapid urbanization. By integrating energy-efficient technologies, sustainable materials, and eco-centric planning, green building principles address critical gaps in informal housing such as inadequate infrastructure and environmental degradation. Among emerging solutions, Building Integrated Photovoltaics combined with greenery (BIPVGREEN) stands out for its dual benefits: generating renewable energy (e.g., through solar panels) and mitigating urban heat islands via vegetation (Lukinov et al., 2024; Mihalakakou et al., 2023). This decentralized approach is ideal for informal settlements, which often lack centralized energy grids. For example, BIPVGREEN systems reduced particulate pollution and used local labor for installation, showing their suitability for low-resource settings. These innovations highlight how green technologies can balance affordability and sustainability, providing scalable options for fair urban development.

Despite green roofs, which involve the integration of plants on building surfaces, provide advantages such as mitigating urban heat island effects, controlling runoff, and enhancing air quality (Adeyemi et al., 2024). There is a growing acceptance and adoption of renewable energy sources such as solar and geothermal systems (Adeyemi et al., 2024; Omole et al., 2024). Nevertheless, obstacles encompass increased upfront costs, limited knowledge about the enduring advantages, and insufficient awareness regarding the lasting benefits of environmental-friendly buildings (Okoro et al., 2023). It is essential to educate the public and industry professionals on sustainable construction's benefits, including increased energy efficiency, lower operating expenses, indoor environmental quality, and improved occupant health and well-being (Borah, 2025; Okoro et al., 2023). This education will promote the widespread use of environmentally friendly building practices.

This holistic approach not only addresses rapid urban expansion but also promotes resilience and sustainability in urban environments (Cao, 2025). Moreover, integrating green building principles into informal settlements can enhance resilience, reduce carbon footprints, and improve the overall quality of life for low-income communities (Adeyemi et al., 2024; Omole et al., 2024). However, despite the potential benefits, the transition from informal settlements to green buildings remains a complex challenge due to financial, technical, social, and policy-related barriers. Addressing these challenges requires a critical examination of existing strategies, stakeholder roles, and innovative solutions that can facilitate large-scale

implementation (Okoro et al., 2023). The discussion highlights the roles of governments, NGOs, and communities, suggesting a holistic view of case study contexts.

This study provides a critical review of the role of transforming informal settlements into green buildings in developing countries. It examines various approaches, including energy-efficient retrofitting, sustainable material use, and community-driven initiatives, while analyzing successful case studies from different regions. Furthermore, this review identifies key challenges, such as financial constraints, governance limitations, and social resistance, which hinder the widespread adoption of green building solutions. By addressing these issues, the study highlights policy recommendations, financing models, and technological innovations necessary to achieve sustainable green building transformation.

2. The Concept and Principles of Green Buildings

Green infrastructure techniques, such as rain gardens, align with efficient water management in green building practices. These methods enhance stormwater management and water quality, ultimately reducing water consumption and protecting local water resources in urban environments (Borah, 2025). Green buildings prioritize reducing energy consumption by incorporating renewable energy sources such as solar or wind power. Advanced HVAC systems can reduce energy demand by up to 50% (Cao, 2025). Energy-efficient appliances and lighting are essential components that enhance overall building performance (Abo El Kasem Ali, 2021). Passive solar design techniques optimize natural light and heat, minimizing reliance on artificial systems (Abo El Kasem Ali, 2021). For instance, the integration of green roofs and solar chimneys has been advocated as an innovative method to cool buildings sustainably, reducing reliance on traditional air conditioning systems.

The selection of building materials significantly impacts a structure's sustainability. Green buildings often use recycled, renewable, and locally sourced materials to minimize environmental impact and transportation emissions. The incorporation of solar panels and wind turbines allows buildings to generate their own energy, reducing dependence on fossil fuels (Nair, 2015). Green roofs and solar chimneys are innovative solutions that improve insulation and promote natural ventilation, further decreasing the need for air conditioning (Nasr et al., 2024). For example, the School of Visual Arts of Oaxaca in Mexico utilized rammed earth and expansive windows to save energy and enhance the learning environment. Green buildings are designed to harmonize with their natural surroundings. This includes minimizing land disturbance, preserving existing natural habitats, and incorporating features like green roofs and urban forestry to enhance biodiversity. Utilizing sustainable materials, such as recycled steel and cross-laminated timber, can lower a building's carbon footprint by 30% - 40% (Cao, 2025). These practices help reduce the urban heat island effect and support local ecosystems.

3. Rationale for Transforming Informal Settlements into Green Buildings

3.1. Environmental Benefits

Green buildings mitigate critical environmental challenges in informal settlements. By incorporating energy-efficient retrofitting and sustainable materials, they reduce urban heat island effects and improve air quality, which is vital in densely populated areas (Karamanis et al., 2024; Nibagwire et al., 2025a, 2025b). For example, retrofitting informal housing with solar-green roofs has been shown to lower indoor temperatures by 5°C, decreasing cooling energy demand by 30% (Lukinov et al., 2024). Additionally, green infrastructure such as vegetative roofs and permeable pavements can reduce flood risks by 40% by managing stormwater runoff (Green et al., 2021). These strategies also contribute to climate mitigation, with retrofits potentially cutting CO₂ emissions by 35% (Niamir et al., 2024), while preserving local ecosystems and enhancing urban biodiversity (Jauhari, 2023).

3.2. Economic Benefits

The economic rationale for green buildings is equally compelling. Sustainable construction can generate 6 - 8 million jobs annually in developing countries by 2030, boosting local economies (Canton, 2021). Low-income households benefit directly, achieving up to 60% savings in energy costs through energy-efficient technologies (Ehimen et al., 2023). Property values in upgraded settlements also rise, providing long-term financial stability for residents (Kamjou et al., 2024). Modular designs and localized material sourcing further reduce costs, making green solutions scalable and affordable. For instance, decentralized solar systems like BIPVGREEN require minimal maintenance and can be adapted using local labor and resources, lowering implementation barriers (Karamanis et al., 2024).

3.3. Social Benefits

Socially, green buildings enhance health, equity, and community resilience. Access to green spaces correlates with improved physical and mental health outcomes, particularly for vulnerable groups like children (Parmar, 2024). Community-driven initiatives, such as participatory planning for green roofs or rain gardens, foster ownership and trust, as seen in projects in Tanzania and India (Oates et al., 2024). Climate-adaptive designs also improve habitability; for example, flood-resistant housing in Bangladesh reduced displacement risks during monsoons (Green et al., 2021). By addressing systemic inequalities such as gender disparities in access to infrastructure, green transformations promote inclusive urban development (UN-Habitat, 2020).

4. Informal Settlements in Developing Countries

4.1. Characteristics and Challenges of Informal Settlements in Developing Countries

Informal settlements, often characterized by inadequate infrastructure and a lack

of essential services, pose significant challenges in urban areas, particularly in developing countries (Dhaka, 2024). These settlements are home to over one billion people, with numbers expected to rise, highlighting the urgent need for effective interventions (UN-Habitat, 2020). The following sections explore the key aspects of informal settlements, including their socio-economic implications, upgrading strategies, and the role of participatory planning. Informal settlements are marked by poverty, overcrowding, and limited access to basic services such as clean water, sanitation, and electricity (Henn et al., 2024). Residents often engage in informal economic activities, which, while crucial for survival, lack job security and benefits associated with formal employment (Venkanna & Sonba, 2024). Higher levels of community participation correlate with more resilient outcomes, fostering a sense of ownership and responsibility among residents (Terdo, 2024). **Figure 1** shows that informal settlements exist in “a state of deregulation”, one where the ownership, use, and purpose of land cannot be fixed and mapped according to any prescribed set of regulations or the law.

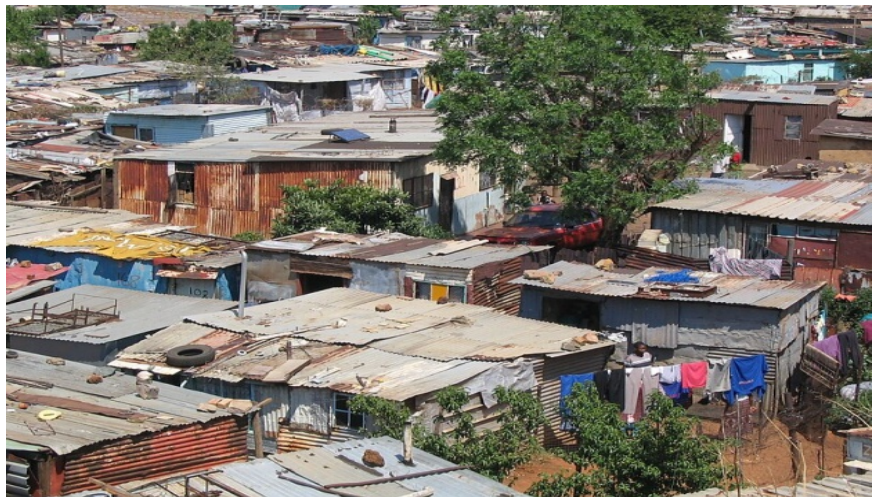


Figure 1. Informal settlements in Soweto, South Africa. (https://en.wikipedia.org/wiki/Informal_housing).

The document includes diverse case studies from Ethiopia, Brazil, Cape Town, and other regions, providing a broad perspective on informal settlements and green building transformations. For instance the overall, the settlement detection analysis identified that informal settlement areas comprised 1720 ha of Cape Town in 2020, representing 0.7% of the city (246,100 ha) (Cinnamon and Noth, 2023). Since Cape Town is a very large city by area, with municipal boundaries capturing many non-residential areas, further area analysis was conducted to examine informal settlement areas in comparison to formal residential land use.

As detailed in **Figure 2** (Cinnamon and Noth, 2023), the top 15 informal settlements in 2020 by total area in hectares in Cape Town, residential parcel data was isolated to determine the size in hectares of just the formal residential areas of the city (38,275 ha), which was added to the overall informal settlement area results

for 2020 to calculate the proportion of all residential areas (formal and informal) considered to be informal at each year. It presents a ranked list of areas (in hectares) for the year 2020, with values ranging from 138.4 ha to 30.4 ha (Cinnamon and Noth, 2023).

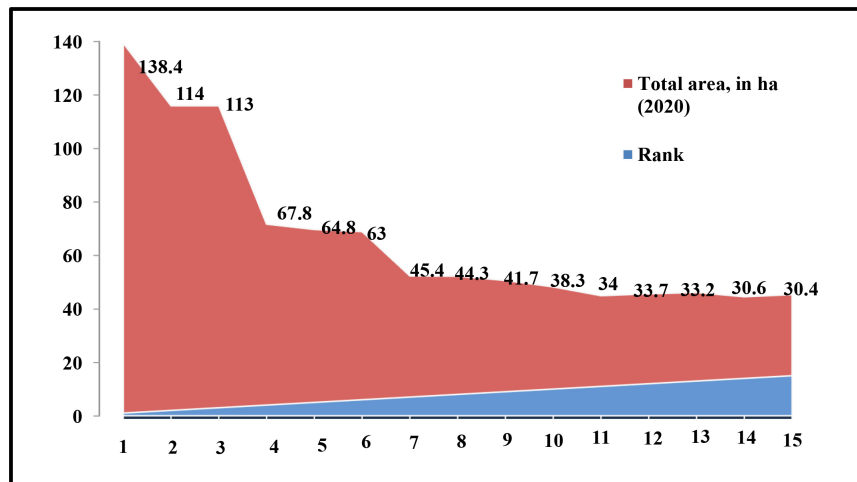


Figure 2. Informal settlements in Cape Town in 2020.

4.2. Drivers behind the Emergence of Informal Settlements

Residents often lack formal ownership or legal rights over the land they occupy, particularly in informal settlements. This situation leads to various challenges, including insecurity of tenure and conflicts over land use. In informal settlements, land rights are often categorized into ownership, use, control, and management, complicating the provision of public infrastructure and services (Mesgar and Ramirez-Lovering, 2021). Many urban residents, especially in China, experience a lack of rights due to the absence of property ownership and urban household registration, which limits their access to public services and participation in community governance (Guo et al., 2021). The absence of formal land rights can lead to disputes, as seen in Ambon City, where residents occupy land without clear ownership, often resulting in conflicts (Matuankotta and Lakburlawal, 2022). While squatters may hold potential ownership rights, the legal system often fails to address their vulnerabilities adequately (Hickey, 2022).

Access to basic amenities such as potable water, sewage disposal, electricity, and roads is often inadequate, particularly for marginalized populations in urban and rural settings. This deficiency is exacerbated by socio-economic disparities, governance issues, and infrastructural neglect. Urban poor face significant barriers to accessing basic services, with inequalities manifesting across different asset quintiles (Kundu et al., 2024). In hilly regions of India, factors like income levels, literacy rates, and housing quality directly influence access to amenities such as piped water and waste management systems (Patra et al., 2023). Inadequate infrastructure severely hampers social and economic development, affecting health and resilience (Patra et al., 2023). Many informal settlements lack reliable access

to electricity and sanitation, with a significant portion of residents relying on communal facilities (Mutymbizi et al., 2020). Poor access to clean water and sanitation leads to health issues, particularly in slum areas where open defecation is common due to inadequate facilities (Lenka, 2022).

Many residents are compelled to live in these settlements due to the lack of affordable housing alternatives, as evidenced by the significant housing backlog in South Africa, where 1.2 million families reside in informal conditions (Makhaye et al., 2021). Overcrowding exacerbates health risks, with poor sanitation and inadequate access to basic services being common issues (Putra et al., 2024). While informal settlements provide immediate housing solutions for many, they also reflect broader socio-economic issues that require comprehensive policy interventions. Addressing these challenges necessitates a multi-sectoral approach that includes sustainable urban planning and community involvement (Marnane, 2021).

5. Green Buildings: Concepts and Benefits

Green buildings represent a pivotal approach to sustainable development, offering numerous benefits that encompass economic, environmental, and social dimensions. These structures are designed to enhance energy efficiency, reduce environmental impact, and improve occupant health, comfort, and well-being. Green buildings can lead to long-term savings through reduced energy and water consumption, with energy-efficient technologies potentially cutting energy demand by up to 50% (Cao, 2025). Beyond economic and environmental advantages, the integration of health-centric design principles such as optimal daylighting, improved indoor air quality, and thermal comfort plays a critical role in fostering occupant satisfaction and well-being.

A growing body of research underscores the importance of daylighting in enhancing occupant health and satisfaction. Natural light regulates circadian rhythms, reduces eye strain, and improves mood and productivity. For instance, Edwards and Torcellin (2002) conducted an empirical study in office environments, revealing that spaces with optimized daylighting reported a 30% increase in occupant satisfaction and a 15% reduction in health complaints such as headaches and fatigue. Similarly, Wargocki and Wyon (2017) found that residential green buildings with enhanced daylighting designs correlated with improved sleep quality and mental well-being, particularly in low-income communities where access to natural light is often limited. These studies highlight the dual benefits of daylighting: reducing energy dependency on artificial lighting while directly contributing to occupant health and comfort. Green buildings also prioritize indoor environmental quality (IEQ) through advanced ventilation systems and low-emission materials, which mitigate respiratory issues and allergies. The holistic design approach ensures thermal comfort, acoustics, and biophilic elements, all of which contribute to a healthier living and working environment.

As depicted in Figure 3, the life cycle of a green building integrates health and well-being at every stage. Architects and engineers incorporate daylighting strat-

egies, non-toxic materials, and biophilic design to enhance occupant comfort. Contractors use sustainable, low-VOC materials to ensure healthy indoor air quality. Building managers optimize natural light utilization and monitor IEQ metrics to maintain occupant well-being. Materials are recycled or repurposed to minimize environmental and health hazards.

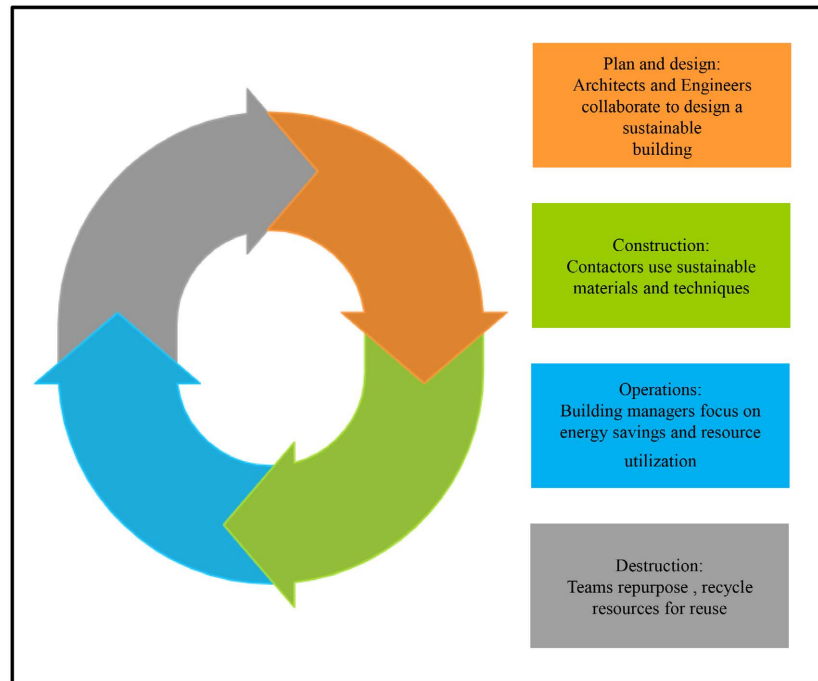


Figure 3. Life cycle of a green building.

6. Sustainable Housing Solutions

The use of eco-friendly materials such as bamboo, recycled bricks, and rammed earth in constructing durable, low-cost housing is gaining traction as a sustainable alternative to traditional building practices. Eco-friendly materials like bamboo and rammed earth are renewable and have lower carbon footprints compared to conventional materials (Chipade et al., 2025; Yahia and Shahjalal, 2024). Although initial costs may be higher, long-term savings arise from reduced energy consumption and maintenance (Yahia and Shahjalal, 2024). Known for its strength and rapid growth, bamboo is used in various structural applications, providing a sustainable alternative to steel (Yahia and Shahjalal, 2024). Utilizing recycled aggregates in brick production minimizes waste and energy consumption, making it a viable option for low-cost housing. This locally sourced material offers excellent thermal mass, regulating indoor temperatures and reducing heating and cooling costs (Chipade et al., 2025).

Implementing energy-efficient designs such as passive cooling, green roofs, and solar panels is crucial for reducing energy consumption in buildings. These strategies not only enhance sustainability but also significantly lower operational costs and environmental impacts. Utilizing building orientation and window placement

can enhance airflow, reducing reliance on mechanical cooling systems (Ayoobi and Inceoğlu, 2024). Strategic use of shading can minimize solar heat gain, leading to substantial energy savings; for instance, optimized window-to-wall ratios can reduce energy loss by up to 58.6% (Ayoobi and Inceoğlu, 2024). Effective insulation combined with reflective materials can lower cooling demands by up to 44% in specific climates (Nogueira et al., 2024). Moreover, these systems provide insulation, reduce heat island effects, and manage storm water, contributing to energy efficiency (Sagar et al., 2025). Integrating renewable energy sources can significantly decrease energy consumption, with studies showing reductions of over 50% in energy costs (Sagar et al., 2025).

7. Strategies for Climate-Resilient Transformation of Informal Settlements

Climate change poses significant challenges to communities worldwide, necessitating a multifaceted approach to mitigate its impacts. Strategies such as retrofitting, community-driven solutions, and policy interventions have emerged as critical tools in addressing these challenges. This response explores these strategies, drawing insights from various research papers to provide a comprehensive understanding of their effectiveness and implementation.

7.1. Retrofitting Strategies

Retrofitting involves modifying existing infrastructure to enhance its resilience against climate change impacts. This approach is particularly effective in urban areas where a significant portion of buildings and infrastructure are already in place. Green retrofitting focuses on reducing the environmental impact of existing buildings by improving energy efficiency and reducing greenhouse gas emissions. Research highlights the importance of policy instruments and financial incentives in promoting green retrofitting. For instance, studies suggest that government subsidies, tax incentives, and low-interest loans can significantly encourage building owners to adopt green retrofitting measures (Zhang, 2023). Additionally, the integration of green technologies, such as energy-efficient systems and renewable energy sources, can further enhance the effectiveness of retrofitting projects (Chen et al., 2024).

7.2. Community-Driven Solutions

Community-driven solutions are integral to building resilience against climate change impacts. These solutions are often tailored to the specific needs and context of local communities, making them more effective and sustainable. The Community-Based Climate Risk Resilience (CBCRR) approach has been successfully implemented in various regions, including Thailand and Indonesia. This approach emphasizes the importance of community and household-level actions in building resilience to climate change. For example, in Thailand's Eastern Economic Corridor, the CBCRR approach has been instrumental in identifying em-

pirical climate resilience actions that can be generalized to other vulnerable communities (Tanwattana and Toyoda, 2024). Similarly, in Indonesia, local governments have played a crucial role in developing policies that support community participation and empowerment, leading to more effective climate resilience strategies (Tanwattana and Toyoda, 2024).

Community-led initiatives have been particularly effective in addressing the unique challenges faced by marginalized communities. For instance, in Boston, communities of color have been at the forefront of climate preparedness and resilience efforts. These initiatives emphasize the importance of listening to community perspectives, engaging in community organizing, and advocating for policy changes to address systemic inequalities (Rivera-Kientz et al., 2024). Similarly, in Nigeria and Senegal, locally-led adaptation initiatives have been recognized as vital components of national climate change adaptation agendas, highlighting the need for national and global support to advance effective local climate action (Okeke, 2023).

7.3. Policy Interventions

Policy interventions play a crucial role in supporting retrofitting and community-driven solutions. Effective policies can create an enabling environment for the implementation of climate resilience strategies. Policy instruments, such as subsidies, tax incentives, and low-interest loans, have been shown to significantly enhance the adoption of green retrofitting measures. For example, in British Columbia, policy strategies and financial incentives have been instrumental in reducing embodied carbon emissions in the building sector (Zhang, 2023). Similarly, in Indonesia, local governments have leveraged policy instruments to promote the development of disaster-resistant infrastructure and sustainable practices. In conclusion, retrofitting, community-driven solutions, and policy interventions are essential strategies for addressing climate change impacts. Retrofitting offers a practical approach to enhancing the resilience of existing infrastructure, while community-driven solutions ensure that climate resilience strategies are tailored to the specific needs of local communities. Policy interventions provide the necessary framework and support for the effective implementation of these strategies. By integrating these approaches, communities can build resilience to climate change impacts and work towards a sustainable future.

Table 1 outlines three key strategies for enhancing sustainability and resilience in buildings. Green retrofitting emphasizes reducing environmental impact by incorporating energy-efficient systems and green technologies. Community-driven solutions underscore the role of local perspectives and policy advocacy in fostering resilience, ensuring interventions align with community needs. Policy interventions leverage financial mechanisms like subsidies, tax incentives, and loans to incentivize green retrofitting and climate-resilient practices. Together, these strategies highlight a multi-faceted approach, combining technological innovation, community engagement, and policy support to advance sustainable building practices.

Table 1. Provides a comparative analysis of key strategies.

Strategy	Description	Reference
Green retrofitting	Focus on reducing environmental impact through energy efficiency and green technologies	(Curtis et al., 2021)
Community-Driven solutions	Highlights the importance of community perspectives and policy advocacy in building resilience.	(Rivera-Kientz et al., 2024)
Policy interventions	Utilizes subsidies, tax incentives, and loans to promote green retrofitting and climate resilience	(Curtis et al., 2021)

8. Social and Behavioral Barriers to the Adoption of Green Building Solutions

While technological, economic, and policy innovations are vital for promoting green building practices, social and behavioral barriers often present equally significant challenges, particularly in informal settlements (Ndlangamandla and Combrinck, 2020). These barriers are frequently underestimated but play a crucial role in shaping the success or failure of sustainable development initiatives. In many informal settlements, residents prioritize immediate survival needs such as shelter, sanitation, and access to basic utilities over long-term environmental considerations. As a result, green building solutions are often met with hesitation or outright rejection. Limited awareness of the benefits of energy-efficient buildings, daylighting, and renewable energy technologies can lead to skepticism and low community-driven adoption.

Furthermore, cultural attachment to traditional building methods and distrust of unfamiliar or externally introduced technologies may deepen resistance, especially when these solutions are perceived as expensive or misaligned with local needs (Watson, 2009). Behavioral resistance is often compounded by a lack of trust in government and external agencies, rooted in past experiences of marginalization or ineffective governance. In such contexts, even well-intentioned green interventions may be perceived as top-down impositions rather than participatory improvements, resulting in low acceptance and poor implementation outcomes.

To effectively address these barriers, it is essential to adopt culturally sensitive, inclusive strategies that prioritize community engagement. Participatory planning, targeted awareness campaigns, and education initiatives can foster greater trust and understanding. Incentivizing behavioral change through social support programs and demonstrating tangible benefits such as cost savings or improved living conditions can also help shift perceptions and increase uptake. Moreover, the success of green technologies depends on aligning innovations with residents' immediate priorities. For instance, financing models like Pay-As-You-Save (PAYS) may be ineffective in regions lacking robust microfinance systems or institutional trust. Similarly, technologies such as BIPV-green roofs may have low adoption if they fail to address concerns around affordability or if materials are inaccessible.

Ultimately, overcoming social and behavioral barriers requires a bottom-up approach that centers on the lived realities of informal settlement communities. Building trust, promoting local ownership, and tailoring solutions to socio-cultural and economic contexts are key to achieving sustainable, long-lasting transformation.

9. Challenges and Barriers

Stronger governmental support, enhanced technical training, and public-private partnerships are essential to overcoming barriers to green building adoption (Imafidon et al., 2024). Financial constraints remain a predominant barrier to the adoption of green building practices and smart technologies in developing countries. High initial investment costs deter stakeholders from committing to sustainable construction projects. For instance, (Zakaria et al., 2024) reported that the significant upfront costs associated with green technologies in Malaysia limit their widespread implementation. Similarly, (Unegbua et al., 2024) highlighted financial limitations in Nigeria, where budget constraints impede the adoption of sustainable practices despite the long-term cost benefits.

Figure 4 highlights critical issues that perpetuate cycles of poverty and exclusion. Weak legal structures contribute to high crime rates and insecurity, leaving residents vulnerable. Social marginalization further isolates these communities, as discriminatory urban policies exclude them from development opportunities. Limited access to essential services, such as healthcare, education, and sanitation, reinforces deprivation, while unstable, low-wage employment restricts economic mobility. Additionally, overcrowding and poor sanitation create significant health risks, facilitating the spread of disease. These interconnected challenges underscore the systemic neglect faced by informal settlement dwellers, necessitating comprehensive policy interventions to improve infrastructure, legal protections, and equitable access to resources.

On the other hand, **Figure 5** reveals a cascade of interconnected issues stemming from inadequate infrastructure and rapid urbanization. Ineffective waste disposal systems result in pollution and heightened health hazards, while the absence of proper drainage exacerbates flooding and soil erosion, destabilizing living conditions. Contaminated water sources and reliance on biomass fuels further degrade both public health and the environment. Additionally, unchecked urban expansion drives deforestation, leading to biodiversity loss and the depletion of green spaces. Poor waste management compounds these problems, manifesting in land degradation, air and water pollution, and diminished ecological resilience. These systemic environmental stressors underscore the urgent need for sustainable urban planning, improved waste management, and equitable access to clean energy and water in informal settlements.

The absence of comprehensive policy frameworks and inconsistent enforcement of existing regulations are critical challenges hindering sustainable building practices. The lack of clear guidelines and supportive policies in Nigeria is a sig-

nificant obstacle (Agboola et al., 2023). Across various African nations, inconsistent policy enforcement undermines efforts to integrate sustainability into project management (Ikejiaku, 2024). The integration of advanced technologies such as AI and IoT into green buildings requires specialized knowledge and skills, which are often scarce in developing countries. Other studies emphasized the shortage of skilled professionals as a barrier to the effective implementation of these technologies (Umoh et al., 2024). Additionally, pointed out technological barriers that prevent the seamless adoption of green technologies.

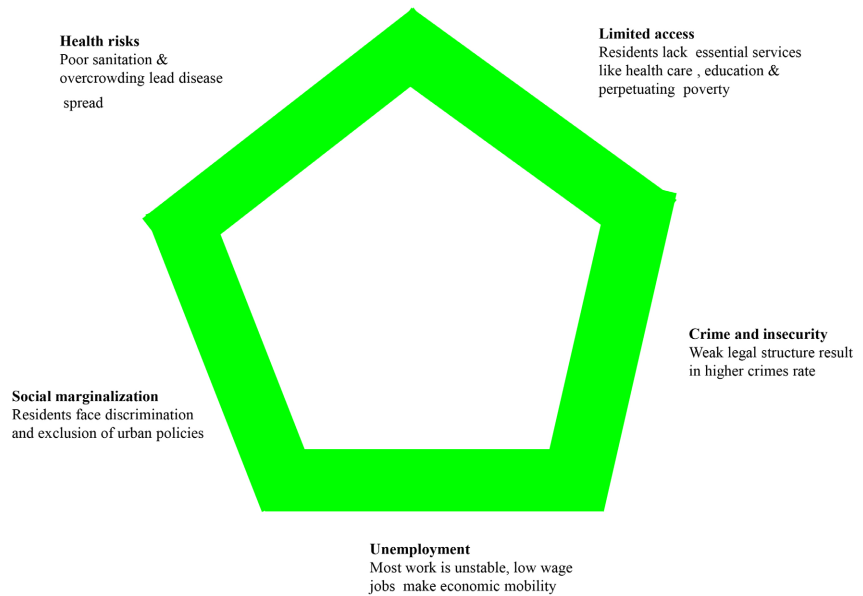


Figure 4. Socioeconomic challenges.

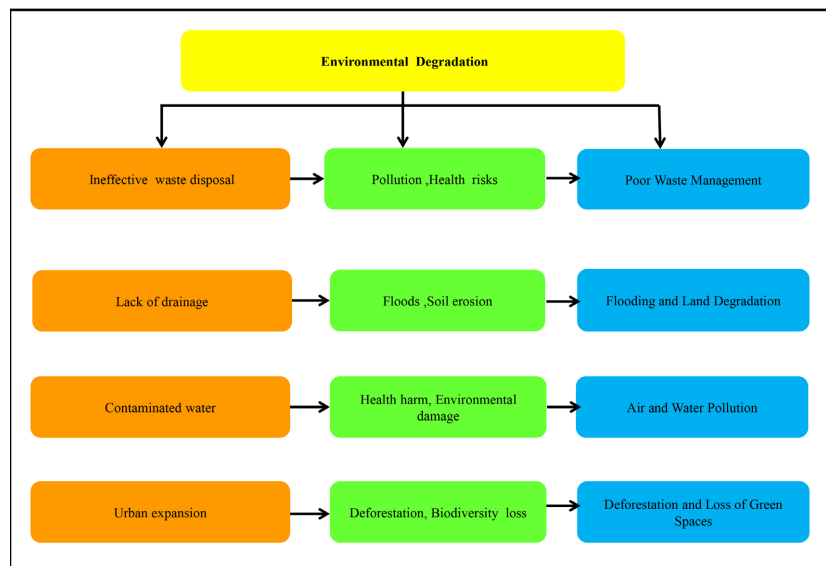


Figure 5. Environmental challenges.

Limited awareness and understanding of green building practices and smart

technologies among stakeholders impede their adoption. Professionals and clients in Nigeria have insufficient knowledge about Green Building Technologies, which reduces their willingness to invest in sustainable practices (Agboola et al., 2023). Despite the challenges, the adoption of green building practices and smart technologies offers substantial benefits that drive their continued implementation. Enhanced energy efficiency, reduced operational costs, improved occupant health, and increased values are among the key advantages identified. (Ejidike and Memomo, 2023) and (Mi, 2024) emphasized the long-term economic and environmental benefits of sustainable construction practices.

Figure 6 illustrates the integration of smart building technologies and green building practices and present significant opportunities for promoting sustainability and energy efficiency in the construction industry, particularly in developing regions such as Sub-Saharan Africa and Nigeria. A framework for enhancing sustainability in the constructed environment via four interrelated components. Sustainable Maintenance prioritizes effective management and preservation to provide enduring environmental and operational advantages. The Collaborative Approach emphasizes the significance of partnerships among stakeholders, such as governments, industry, and communities, to disseminate information and expedite the adoption of sustainable technology. Government policies are essential in setting rules, incentives, and financial assistance to promote sustainable activities. Ultimately, Research and Development emphasizes innovation by investing in economical and scalable solutions to address difficulties in sustainable building. Collectively, these components comprise a comprehensive plan for attaining sustainability, harmonizing practical execution, governmental endorsement, technical progress, and cooperative endeavor.

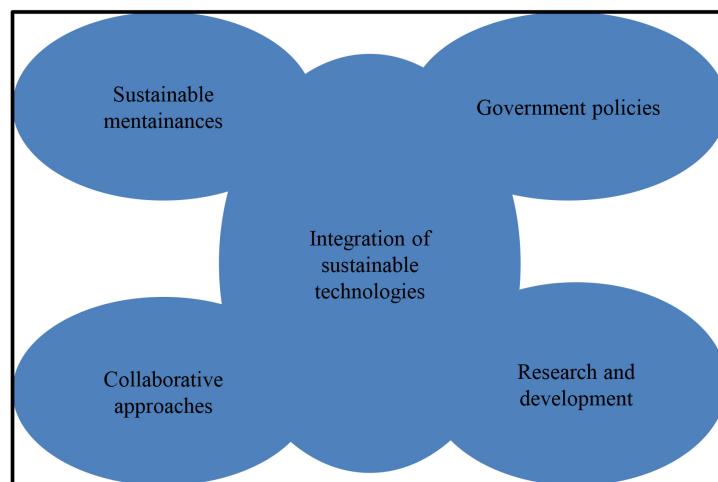


Figure 6. Integration of sustainable technologies.

10. Role of Stakeholders

The transformation of informal settlements into green buildings in developing countries involves a complex interplay of various stakeholders, including govern-

ment entities, private sector players, NGOs, and local communities. Each stakeholder group plays a distinct role in facilitating this transformation, contributing to sustainable urban development. Effective collaboration and engagement among these stakeholders are crucial for overcoming barriers and ensuring the successful implementation of green building practices.

10.1. Government Role

The construction sector is a significant contributor to global environmental challenges, including resource depletion, energy consumption, and greenhouse gas emissions. To address these issues, governments worldwide have implemented various regulations and policies to promote green building practices. These measures include setting standards, providing financial incentives, and creating tax breaks to encourage sustainable construction. Governments are pivotal in setting regulations and policies that promote green building practices. They can provide incentives, subsidies, and tax breaks to encourage the adoption of sustainable construction methods (Rasa, 2023). For instance, the Building and Construction Authority's (BCA) Green Mark Scheme in Singapore has been instrumental in driving environmental sustainability in the construction industry. This scheme sets clear standards for energy efficiency, water conservation, and environmental quality, ensuring that new constructions meet established sustainability criteria (Mahmud et al., 2024).

Governments play a crucial role in promoting green building practices through the establishment of regulatory frameworks, the provision of financial incentives, and international cooperation. By setting clear standards, providing subsidies and tax breaks, and encouraging sustainable technologies, governments can create an environment where green buildings become the norm rather than the exception. Future efforts should focus on optimizing policy frameworks, enhancing financial support, and fostering international collaboration to achieve global sustainability goals.

10.2. Private Sector Involvement

The private sector plays a pivotal role in driving innovation and investment in green technologies and construction practices, essential for aligning with the Sustainable Development Goals (SDGs). Their involvement not only fosters economic growth but also enhances environmental stewardship through the adoption of sustainable practices. This response will explore the significance of private sector participation, the benefits of green construction, and the challenges faced in this transition. The private sector is increasingly engaging with SDGs, recognizing the potential for sustainable business models that align with environmental goals (van der Waal, 2024).

Collaborative ecosystems involving businesses, researchers, and policymakers are crucial for accelerating the commercialization of green technologies (Ngoc et al., 2024). Green construction practices reduce carbon emissions and resource de-

pletion while improving project efficiency (Nwaogbe et al., 2025). However, High upfront costs and regulatory barriers hinder the adoption of green practices (Nwaogbe et al., 2025) and Solutions include strengthening policy frameworks, enhancing public-private partnerships, and providing specialized training programs to bridge skill gaps. While the private sector's engagement in green technologies is promising, challenges remain in ensuring that these efforts translate into substantial impacts on sustainability. A more strategic integration of SDGs into core business practices is necessary for meaningful progress.

10.3. NGOs and Community Engagement

NGOs significantly contribute to raising awareness and educating communities about the benefits of green buildings, particularly in regions facing environmental challenges. They serve as vital intermediaries, disseminating information and promoting sustainable practices that enhance energy efficiency and reduce environmental impacts. This role is crucial in fostering community engagement and understanding of green building benefits. NGOs engage in knowledge diffusion, helping communities understand the importance of green buildings in combating climate change and promoting sustainability (Elayah et al., 2024). Green buildings are associated with reduced operating costs, improved occupant health, and increased property values, which NGOs highlight to encourage adoption (Baerom et al., 2025). Despite their efforts, NGOs often face challenges such as limited resources and regulatory restrictions, which can hinder their effectiveness in promoting green building initiatives (Parveen, 2024). While NGOs play a crucial role in promoting green buildings, it is essential to recognize that their impact can be limited by external factors such as government policies and market readiness. Addressing these challenges requires collaborative efforts among stakeholders to create a conducive environment for sustainable practices.

11. Synthesis of Green Infrastructure, Technological Innovations, and Policy Frameworks

11.1. Integration of Green Infrastructure

The effectiveness of strategies for transforming informal settlements green infrastructure (GI), technological innovations, and policy frameworks depends on local governance, economic conditions, and community engagement. For example, decentralized solar systems (e.g., BIPVGREEN) succeed in participatory governance contexts (Oates et al., 2024), while weak institutions or limited funding hinder scalability (Ndlangamandla and Combrinck, 2020). Similarly, community-driven initiatives require trust and cultural sensitivity to avoid failure (Watson, 2009). This variability necessitates adaptive, context-specific approaches. Among these strategies, green infrastructure (GI) mitigates environmental risks in informal settlements by improving air quality, managing stormwater, and enhancing resilience. GI integrates natural systems (e.g., green roofs, rain gardens) to reduce runoff by up to 79% (Godyn et al., 2024) and filter pollutants through vegetation.

Defined as interconnected networks that sustain natural processes, GI components vary by ecological priorities and human interaction levels.

Figure 7 outlines the five essential components, each contributing uniquely to ecological sustainability and land management. Managed native landscapes prioritize the preservation and restoration of indigenous ecosystems, frequently including conservationists and local populations. Reserves are designated areas established by governmental or environmental entities to preserve biodiversity. Parks and open spaces offer recreational and ecological advantages, usually overseen by local authorities or park services. Working landscapes, including agricultural and forested areas, harmonize production with sustainability, necessitating cooperation among landowners, farmers, and politicians. Finally, recycled lands entail the recycling of deteriorated or abandoned places for novel ecological or community applications, sometimes spearheaded by urban planners and environmental organizations. Collectively, these components provide an integrated system that fosters environmental health, economic sustainability, and social welfare through collaborative initiatives among many stakeholders.

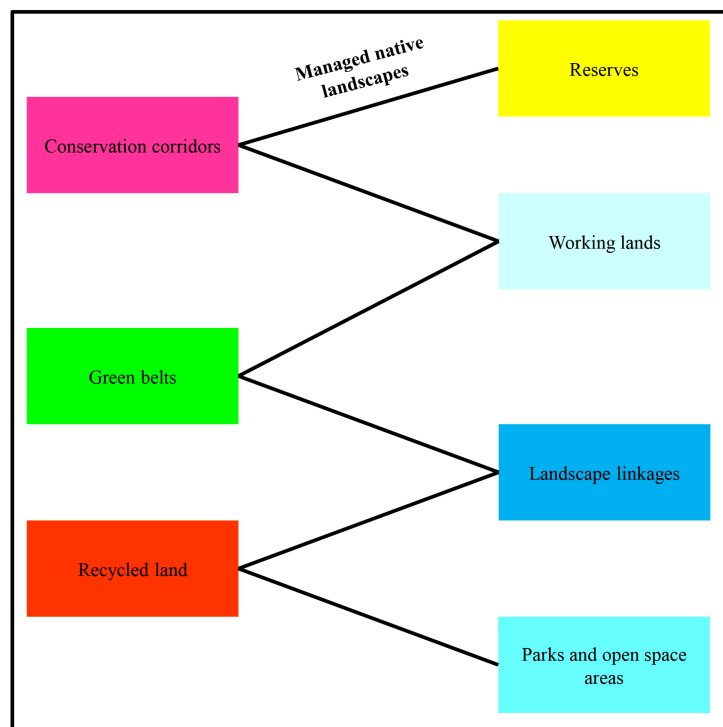


Figure 7. Conceptual green building system.

Table 2 highlights diverse approaches to achieving sustainability in construction by integrating green building. Comparative analysis of green building policy incentives and sustainability outcomes by Region/Country summarizes key policies, outcomes, and references for various regions. Singapore's Green Mark Scheme and mandatory codes have enhanced energy efficiency, while China's subsidies and penalties drive green building adoption. India uses tax incentives to promote

green technology, and the UK leverages grants and green bonds to meet consumer demand. The US focuses on LEED certification, and the EU's Green Deal Policy aims for carbon neutrality.

Economically, in **Table 3** (Qoraney et al., 2024) represents in reducing or replacing costly gray infrastructure. The reduction in cost between the two systems (informal settlement & green building) due to changes in the percent of the used GRs and this effect will be noticeable and clear with big values more than this mentioned one in the big areas as in this study, the used positive system is a local system with diameter “315 mm and 400 mm” so the cost of using the GI almost the same when 60% of the plot roof area is used as a GR also the generated runoff volume reduced by 72% than the concrete roof, as the compare with a positive system with pipe diameter up to 400 mm, significant cost reductions will be observed in large areas and extensive storm water networks with large diameters. In such cases, the cost of the positive system becomes significantly higher than the GI system due to the large diameter and depths of the network. Also, in the case study, the area is not big enough to declare the reduction effect between the two systems, but cost reduction still exists. For example, when 50% of the plot roof area is used as a GR, the cost reduction is 10%. The reduction in generated runoff volume was 64%, and when 30% of the plot roof area was used as GR, the cost reduction was 37%, and the reduction in generated runoff volume was 47%. Also, increasing groundwater resources, as most of the rainfall will be infiltrated via these elements, will reduce water treatment costs and the added value of the developed area.

Table 2. Comparative analysis of green building policy incentives and sustainability outcomes by Country/Region.

Region/ Country	Key Policies/ Incentives	Outcomes and Insights	References
Singapore	Green Mark Scheme, Mandatory Codes	Significant improvements in energy efficiency and resource management	(Mahmud et al., 2024)
China	Subsidies for Developers and Homebuyers	Promotes green building adoption, especially when combined with penalties	(Fan and Li, 2024)
India	Tax Credits, Indirect Tax Exemptions	Encourages green technology adoption, addresses knowledge gaps	(Kumar et al., 2024)
United Kingdom	Grants, Tax Credits, Green Bonds	Drives sustainable practice consumer demand	(Akin and Akin, 2024)
United States	LEED Certification, Green Building Codes		(El-Hakim and AbouZeid, 2024)
European Union	Green Deal Policy, Subsidies, Tax Benefits	Promoting carbon neutrality inspires global initiatives	(El-Hakim and AbouZeid, 2024)

Table 3. Comparison between GI and traditional system.

Traditional infrastructure system	Green infrastructure system	% Reduction of cost	
COST (AED)	% Use of green roof	COST (AED)	
2,695,866	25%	1,522,592	44%
	30%	1,702,603	37%
	40%	2,062,626	23%
	50%	2,422,563	10%
	60%	2,782,672	-3%

11.2. Technological Innovations

Building Integrated Photovoltaics combined with urban greenery (BIPVGREEN) offers a transformative approach to enhancing energy efficiency and environmental quality in informal settlements. This integration not only generates renewable energy but also improves urban aesthetics, mitigates heat islands, and supports sustainability. BIPVGREEN systems utilize building surfaces for solar energy while incorporating greenery, which cools panels through shading and evapotranspiration, thereby increasing efficiency and reducing reliance on fossil fuels (Karamanis et al., 2024; Wang et al., 2023).

Recent studies highlight the practical benefits of BIPVGREEN. For instance, a 2023 study found that solar-green roofs in low-income areas could lower indoor temperatures by up to 5°C, reducing cooling energy demand by approximately 30% (Lukinov et al., 2024; Mihalakakou et al., 2023). Similarly, a 2024 case from Brazil demonstrated that PV-integrated green walls produce electricity and decrease particulate matter pollution by 15%, improving air quality (Karamanis et al., 2024). These systems support local materials and labor, fostering job creation and community involvement, which are vital for sustainability. In addition, vegetation on green roofs can increase PV module efficiency by about 2% in tropical environments, further boosting energy gains (Kaewpraek et al., 2021). This integrated approach also offers environmental benefits such as stormwater management, urban heat island reduction, and biodiversity support, making it a comprehensive solution for green building design.

Figure 8 (Dallas et al., 2020) illustrates how a Building-Integrated Photovoltaic Vegetative (BIPV) green roof combines solar energy production with green roof technologies. It works by regulating the surface temperature of PV panels; vegetation naturally cools the panels through shading and evapotranspiration, enhancing their performance. The green roof infrastructure includes layers for vegetation, growth substrate, soil erosion prevention, water drainage, root barriers, and waterproofing, creating a symbiotic system that improves photovoltaic efficiency and environmental quality. Despite its advantages, widespread adoption faces challenges such as financial constraints, limited technical expertise, and the need for community engagement. Implementing smart technologies can enhance sustainability by optimizing resource management and integrating renewable energy

sources (Billanes et al., 2025). Addressing these barriers through awareness and capacity building is crucial for maximizing the benefits of BIPVGREEN in informal settlements.

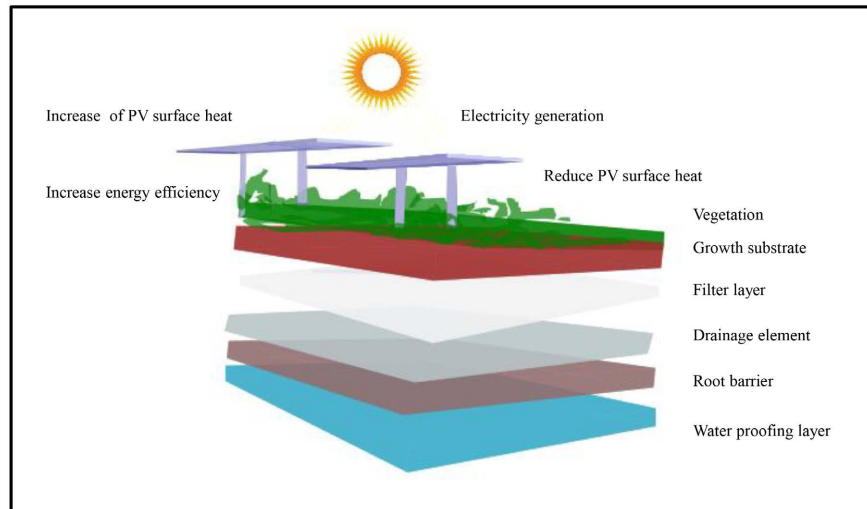


Figure 8. The working principles of a BIPV-green roof.

11.3. Policy and Governance

The transformation of informal settlements into green buildings is a critical challenge for urban development globally. Local governments play a pivotal role in coordinating resources and technologies to achieve this transformation. Participatory planning is a cornerstone of successful informal settlement upgrading. By involving residents in the planning process, local governments can ensure that the solutions are tailored to the community's needs and aspirations. Research from Tanzania and India demonstrates that community-led housing initiatives, with appropriate state support, can significantly improve the quality of life for vulnerable populations. These initiatives often involve participatory planning approaches, which integrate local knowledge and community feedback into the decision-making process (Oates et al., 2024).

Effective policy frameworks and governance structures are essential for coordinating resources and technologies in informal settlement upgrading. These frameworks should promote transparency, accountability, and stakeholder participation, ensuring that the upgrading process is both inclusive and sustainable. Local governments can effectively coordinate resources and technologies to transform informal settlements into green buildings by adopting a combination of participatory planning, innovative technologies, public-private partnerships, inclusive zoning, and robust policy frameworks. These strategies, supported by case studies from around the world, demonstrate the potential for creating inclusive, resilient, and sustainable urban environments. By fostering collaboration between governments, communities, and private actors, local governments can address the challenges of informal settlements and promote sustainable urban development.

12. Conclusion

Transforming informal settlements into green buildings is indispensable for achieving sustainable urbanization in developing countries. While green building principles, energy efficiency, sustainable materials, and water conservation address critical challenges such as environmental degradation and social inequality, their widespread adoption faces persistent barriers. Financial constraints, fragmented governance, technological gaps, and social resistance demand a coordinated, multi-stakeholder approach. Governments must prioritize policy reforms that embed green standards into national housing agendas, supported by financing mechanisms like public-private partnerships, subsidies, and micro-financing to ensure affordability. Equally vital is fostering community-driven engagement to align solutions with local needs, ensuring social acceptance and long-term sustainability. Future efforts should focus on scalable innovations, such as modular designs and decentralized renewable energy systems (e.g., BIPVGREEN), which balance cost-effectiveness with ecological resilience. Comparative policy analyses can identify best practices for integrating green infrastructure, while empirical studies must evaluate the socio-economic impacts of interventions in diverse contexts. Urgent action is imperative: proactive investment in these strategies can mitigate escalating urban poverty, reduce carbon footprints, and enhance livability for vulnerable populations. Ultimately, bridging gaps in financing, digital planning tools, and climate adaptation requires interdisciplinary collaboration. Policymakers, researchers, and practitioners must unite to advance context-sensitive solutions that harmonize technological innovation, grassroots participation, and equitable governance. By prioritizing inclusive and resilient urban transitions, stakeholders can transform informal settlements into engines of ecological and social progress, ensuring sustainable development for rapidly growing cities.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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