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Modern Energy Sources for Sustainable Buildings: Innovations and Energy Efficiency in Green Construction

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Abstract: Faced with increasing challenges related to energy efficiency and sustainable development, green buildings play a pivotal role in reducing energy consumption and lowering carbon dioxide (CO_2) emissions. This article reviews modern energy sources, including renewable systems such as solar, wind, and geothermal energy, and their applications in green construction. This literature review synthesizes the latest research and trends, focusing on the efficiency and reliability of these technologies. Furthermore, this study examines innovative energy management methods, such as smart grids (SGs) and energy storage solutions (ESSs), that support the development of sustainable buildings. The findings highlight the significant potential of modern energy sources to improve energy efficiency and reduce environmental impacts. Additionally, this study addresses the challenges associated with implementing these technologies and the necessity of integrating renewable solutions into large-scale energy management systems. The final conclusions emphasize future directions in green construction, underscoring the importance of innovation and cross-sector collaboration to achieve a sustainable future.

Keywords: renewable energy; green buildings; energy efficiency

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1. Introduction

The contemporary world is confronted with major challenges related to climate change, sustainable development, and escalating energy costs. According to the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA), the building sector accounts for approximately 39% of global CO_2 emissions, making it a critical area for reducing emissions and adapting to climate change [1,2]. In this context, green buildings offer innovative solutions that minimize energy consumption while improving the quality of life for residents.

Sustainable construction incorporates advanced technologies and materials to improve energy efficiency and reduce environmental impacts. Key innovations include renewable energy systems such as photovoltaic (PV), wind turbines, and geothermal heating, which have become integral elements of modern building design [3–5]. Additionally, research highlights the increasing role of hydrogen fuel cells in sustainable energy solutions [6].

Energy Service Companies (ESCOs) are gaining popularity as a viable model for implementing energy efficiency projects in the building sector, particularly in China, where strategic frameworks have been developed to optimize their application [7]. Moreover, hybrid energy systems, which integrate multiple renewable sources such as PV and wind energy, have demonstrated high effectiveness in enhancing energy reliability and efficiency [8].

In addition to energy generation, the concept of gravitational energy storage is emerging as a promising solution for urban energy stability, allowing surplus energy to be stored and released when needed [9]. At the same time, smart grids (SG) and automation technologies enable real-time energy distribution and optimization, improving the overall energy efficiency of sustainable buildings [10].

This study employs a modified PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology, adapted to the specificity of green building technology research. PRISMA is a widely used review framework that allows for precise inclusion and exclusion criteria, facilitating the objective selection of the relevant literature. This approach is used to identify, analyze, and compare state-of-the-art energy technologies in sustainable construction, as well as to provide numerical summaries and a critical comparison of active and passive energy solutions [11].

Using PRISMA as the research methodology, this study aims to assess both the current state of knowledge and the practical applicability of green technologies in construction. This framework also allows for the identification of research gaps and the formulation of recommendations for future studies in this area. The primary objective of this research is to analyze advanced energy sources in the context of sustainable building, with particular emphasis on their efficiency, reliability, and cost-effectiveness [12].

A systematic review of the literature was conducted to identify key trends, research gaps, and challenges associated with the implementation of these technologies. Addressing these factors is essential to assessing the actual impact of these technologies on reducing emissions, lowering operating costs, and improving the building user experience.

The article is divided into several key sections. Section 2 presents an in-depth review of emerging energy technologies and their potential applications in sustainable construction, including real-world case studies. Section 3 discusses integrated approaches to energy management in buildings, while Section 6 provides a comprehensive cost–benefit analysis of implementing such technologies. Finally, Sections 8 and 9 offer discussions and conclusions on the future of sustainable building development.

2. Emerging Technologies

As climate change accelerates and the need for sustainability intensifies, advanced energy sources are becoming essential components of green buildings. This section discusses selected technologies that have the potential to revolutionize energy supply strategies in buildings, along with their associated costs and benefits.

2.1. Fuel Cells

Fuel cells, which are increasingly accessible, have the potential to generate sustainable electricity and heat. Their ability to produce energy through electrochemical reactions with minimal environmental impact could make them a promising alternative to conventional energy sources. For example, residential fuel cell systems in South Korea, such as hydrogen-based units, have been shown to generate up to 5 kW of electricity and heat, which is sufficient to power an average household [4,13].

2.2. Biomass Energy

Biomass energy, derived from organic materials, serves as a renewable resource that promotes sustainability and reduces waste. Modern biomass boilers achieve efficiencies of 85–90%, and some studies have shown that they can reduce CO_2 emissions by up to 90% compared to conventional fossil fuel systems [3]. For example, in Sweden, biomass contributes more than 50% of district heating production, which demonstrates its large-scale potential [14].

2.3. Geothermal Heating and Heat Pumps

Geothermal energy systems have the potential to offer an efficient means of reducing energy consumption by harnessing heat from the earth's crust. Studies suggest that geothermal heating systems may be able to reduce energy demand by 30–50% compared to traditional heating solutions [5,15,16]. In Poland, geothermal infrastructure in spa towns like Uniejów demonstrate the adaptability of these systems to local conditions [17].

2.4. Hybrid Energy Systems

It seems that the integration of multiple renewable energy sources is becoming increasingly popular. Hybrid systems that combine photovoltaic (PV) with wind energy appear to offer significant efficiency improvements. In Germany, for example, buildings that use photovoltaic (PV) and wind turbines with energy storage exhibit a 40% higher energy efficiency than those that rely solely on one renewable source [6,18].

2.5. Gravity-Based Energy Storage

Gravity-based energy storage systems, such as those that lift and lower heavy masses to generate power, present novel grid stabilization solutions. Projects such as Gravitricity in Scotland, which has the capacity to store up to 50 MWh of energy, have the potential to facilitate the integration of renewable energy sources into urban grids [7,19].

3. Integrated Approach

The integration of various energy sources in green buildings brings numerous economic and environmental benefits. An example of this approach is the combination of photovoltaic (PV) and wind energy systems. This hybrid configuration maximizes the utilization of available energy resources, regardless of the time of day or prevailing weather conditions [1,2]. During daylight hours, energy is generated primarily by photovoltaic (PV), while at night or during cloudy periods, wind turbines ensure a continuous supply of power [3,20].

Another example of an integrated approach is the implementation of energy management systems that monitor and optimize a building's energy consumption, thereby enhancing overall efficiency. These systems might regulate energy production and facilitate effective storage and distribution, which could be crucial for maintaining the energy stability of the building. In summary, modern energy sources and their integrated application could play a fundamental role in transitioning the building sector towards sustainability. By taking advantage of innovative technologies and their synergies, we believe that we have the opportunity to not only meet the energy demands of buildings, but also to mitigate their environmental impact and enhance the quality of life for their residents.

4. Modern Energy Sources

Modern energy sources such as solar, wind, geothermal, and gravitational energy have become essential components of sustainable building systems. Extensive research highlights the benefits of integrating these technologies into architectural projects, leading to substantial reductions in energy consumption and greenhouse gas emissions.

4.1. Solar Energy

The integration of photovoltaic (PV) panels into residential and commercial buildings significantly improves energy efficiency. Recent advances include transparent solar cells (Figure 1), which can be embedded in windows [6,7]. These technologies enable energy generation without compromising architectural esthetics. Moreover, integrating photovoltaic (PV) systems into commercial buildings significantly enhances their energy efficiency, leading to substantial cost savings [8,9].

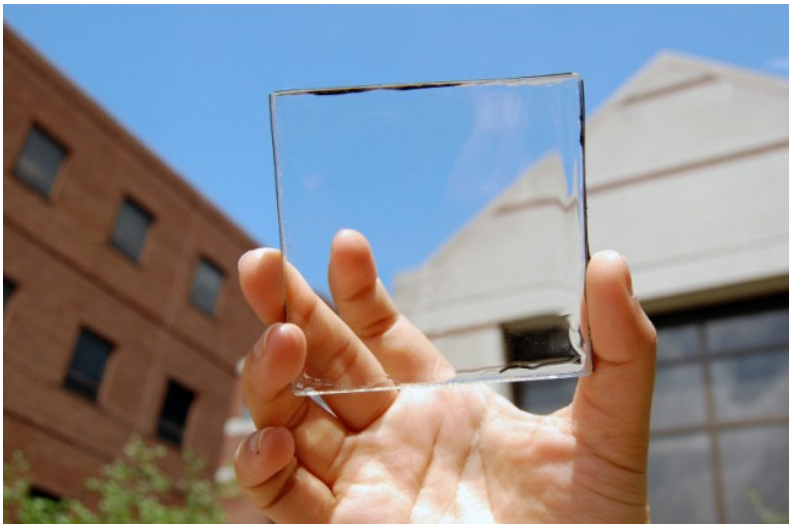

Figure 1. Fully transparent solar concentrator [21].

Perovskite solar cells have gained traction as an innovative material for solar panel production due to their high efficiency and low manufacturing costs (Figure 2). With their superior solar energy conversion rates, perovskite-based cells present a promising alternative to conventional silicon panels [10,11]. Their adoption in buildings can considerably decrease the reliance on external energy sources, a critical factor given the growing global demand for electricity.

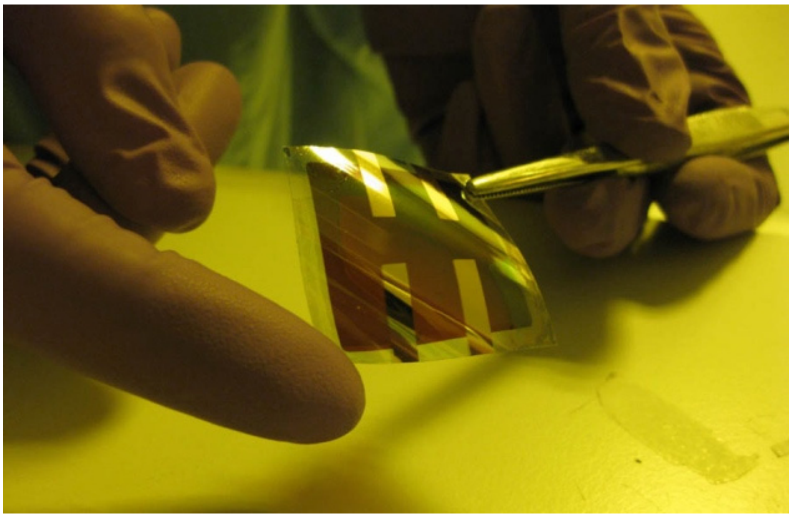

Figure 2. Perovskite solar cells [22].

4.2. Wind Energy

Wind turbines (Figure 3) are a viable renewable energy solution, particularly in areas with favorable wind conditions. Studies indicate that the incorporation of wind energy systems into buildings improves energy efficiency and reduces emissions [12,13]. Small-scale wind turbines are especially well-suited for urban environments, offering a relatively reliable energy source even in regions with moderate wind speeds. These turbines are designed to be both esthetically attractive and structurally compatible with modern buildings [14,15,23].

Figure 3. SheerWind's INVELOX tunnel-based wind turbine [4].

4.3. Geothermal Energy

Geothermal energy systems, which harness heat from the Earth's crust, provide an efficient means of reducing energy consumption. Research suggests that geothermal heating and cooling systems can reduce energy consumption by 30–50% compared to conventional heating systems [16,17]. These systems provide stable thermal regulation, thus reducing dependence on traditional energy sources. Furthermore, integrating geothermal technologies with other renewable solutions, such as heat pumps, can further improve energy efficiency and cost-effectiveness [18,19,24,25].

4.4. Gravity Energy Generators

Gravity energy generators use potential gravitational energy, similar to hydroelectric storage systems. Modern applications involve lifting heavy masses (e.g., concrete blocks) to higher elevations and then releasing them to generate energy (Figure 4). These systems offer rapid energy production, making them an ideal complement to variable renewable sources such as solar and wind power. Furthermore, a gravity-based energy storage system improves grid stability by storing surplus energy and releasing it when demand increases [18,19,26].

Figure 4. Gravitational lamp "Gravia" created by Clay Moulton [9].

5. Smart Technologies and Energy Management

Smart technologies in energy management play a crucial role in the pursuit of sustainable construction. The literature increasingly highlights that the implementation of modern automation and energy management systems in buildings leads to significant energy savings and reductions in operating costs. Solutions such as building automation systems, sensors, and Internet of Things (IoT) devices enable effective monitoring, control, and optimization of energy consumption, supporting the achievement of sustainability goals [3,27].

5.1. Efficiency and Benefits

Studies by Zhou and Merabet, suggest that smart energy management systems can reduce energy consumption by up to 30% by optimizing device operation and better adapting performance to user needs [27,28]. Machine learning techniques and data analysis allow these systems to make automated decisions, which could further increase efficiency. For example, buildings that use systems based on artificial intelligence can automatically adjust heating and cooling depending on the presence of the occupant, weather conditions, and previous patterns of energy consumption [29]. Meanwhile, Powell et al emphasize the benefits of integrating smart grid technologies with traditional heating and cooling systems. This could improve the management and efficiency of various energy sources, including renewables like solar and wind power [9,28,30,31].

5.2. Monitoring and Data Analysis

Advanced technology can facilitate energy consumption monitoring and data analysis, allowing for the identification of areas needing improvement. For example, smart energy meters can provide real-time data, allowing users to track consumption and make informed energy-saving decisions [32,33]. Furthermore, data analysis can support the prediction of energy demand, which is crucial for planning and managing energy supply in buildings [34].

A case study in Singapore demonstrates how advanced algorithms might analyze energy consumption patterns and real-time device operating adjustments. This approach has contributed to a 25% reduction in energy use, while also enhancing occupant comfort [35,36].

5.3. Analysis Supporting Sustainable Development

The application of smart technologies could be a potential factor in achieving these goals [37]. It has been suggested that these technologies can improve energy management, which may result in reduced CO_2 emissions and a minimized environmental impact of buildings. For example, there are smart buildings in Masdar City, United Arab Emirates, that integrate renewable energy sources with advanced automation systems, achieving near net-zero emissions [38,39].

Public support through financial programs and regulations can promote the adoption of smart technologies, such as tax incentives and subsidies for energy management systems, accelerating their implementation [40,41].

Conclusion: Smart technologies form the foundation for modern and sustainable construction. Their implementation can enable significant energy savings, enhance user comfort, and reduce environmental impact. It is therefore recommended that efforts be made to support the development of these technologies and their integration with renewable energy sources, as this would contribute to the future of the construction sector [42,43].

6. Examples of Renewable Energy Applications

It has been observed that a growing number of construction projects around the world seem to suggest certain benefits that may be associated with the use of modern energy sources. These initiatives appear to demonstrate that renewable technologies may be effectively integrated into diverse architectural projects, regardless of local climatic or geographical conditions. Below are examples of buildings whose design and operation may serve as models of sustainability and energy efficiency.

6.1. Bullitt Center, Seattle, DC, USA

The Bullitt Center, known as 'the world's most sustainable office building' (Figure 5), relies on solar energy and rainwater to meet its energy and water needs. The building features a rooftop photovoltaic system that generates electricity, while rainwater harvesting reduces the demand for potable water. It is a Net Zero Energy building, which means that it produces more energy annually than it consumes [44,45]. In addition, the project maximizes energy efficiency by using natural lighting and ventilation.

Figure 5. Bullitt Center, Seattle, DC, USA [46].

6.2. The Edge, Amsterdam, The Netherlands

The Edge (Figure 6) is an office building in Amsterdam that integrates advanced energy technologies, including photovoltaic (PV) systems and intelligent energy management systems. It uses solar energy and its advanced systems optimize energy consumption, significantly increasing the energy efficiency of the building [47,48]. Thanks to smart building technology, The Edge has achieved one of the highest energy efficiency ratings in the world.

Figure 6. The Edge, Amsterdam, The Netherlands [49].

6.3. Bosco Verticale, Milan, Italy

Bosco Verticale (Figure 7) is a pair of residential towers in Milan covered with lush vegetation. Plants not only improve air quality but also help reduce carbon dioxide (CO_2) emissions. The buildings are equipped with photovoltaic (PV) panels that generate energy for residents' needs [50,51]. In addition, irrigation systems use rainwater, reducing the demand for potable water. Bosco Verticale is an excellent example of how sustainability can be combined with esthetics and functionality in densely populated cities.

Figure 7. Bosco Verticale, Porta Nuova District, Milan, Italy [52].

6.4. One Central Park, Sydney, Australia

One Central Park (Figure 8) is a project that integrates sustainable architecture with renewable energy sources. The building uses photovoltaic (PV) and water recycling systems, which have the potential to reduce its carbon footprint [53]. Additionally, green terraces and shared spaces improve the microclimate, promote social interaction, and enhance residents' quality of life.

Figure 8. One Central Park, Sydney, Australia [54].

These examples highlight the diversity of applications for renewable energy technologies in buildings, demonstrating that sustainable architecture can meet various mental and social needs while contributing to the global transition towards cleaner and greener urban spaces.

7. Justification for Investing in Modern Energy Sources

Modern energy sources, such as solar, wind, geothermal, and gravitational energy, offer significant benefits essential for sustainable development. Implementing these technologies helps reduce CO_2 emissions and natural resource consumption. Studies show that buildings equipped with renewable energy systems can achieve operational savings of up to 50% [55,56]. In addition, investments in modern energy technologies provide social and environmental benefits, supporting job creation in the green technology, engineering, and construction sectors.

According to a report by the International Renewable Energy Agency (IRENA), in 2020, global employment in the renewable energy sector reached 11.5 million jobs, emphasizing the growing role of this sector in the economy [57].

7.1. Costs Compared to Traditional Solutions

The initial costs of modern technologies can be higher compared to traditional systems; however, long-term savings can offset these expenses. For example, the cost of installing photovoltaic panels has decreased by approximately 82% since 2010, making them increasingly accessible to investors [58].

Further savings result from decreasing operational costs: energy management systems automatically adjust energy consumption based on weather and demand, further improving economic efficiency in buildings. Furthermore, the development of microgrids and decentralized energy systems allows local communities to generate energy independently, reducing their dependence on centralized energy sources [59].

7.2. Cost–Benefit Analysis

Investing in renewable energy sources offers significant financial benefits beyond immediate savings. For example, buildings powered by renewable energy systems often experience an increase in property value. Studies conducted in the United States indicate that homes equipped with solar energy systems sell for an average of 17% more than comparable properties without such systems [60].

Furthermore, communities investing in renewable energy sources can achieve greater energy independence and resilience against fluctuations in fossil fuel prices. Reducing dependence on conventional energy sources also minimizes the risks associated with market instability [61].

7.3. Operating Costs—Comparative Table

Table 1 compares initial costs, operating expenses, advantages, disadvantages, and applications of various energy technologies in sustainable construction.

Table 1. Comparison of energy technologies.

Technology	Initial Costs (USD/kW)	Operating Costs (USD/Year)	Advantages	Disadvantages	Example Applications
Photovoltaics (PV)	3000–6000	<200	CO_2 emission reduction, fuel independence	No production at night, requires storage	Bullitt Center, Seattle, DC, USA [62]
Wind Energy	10,000+	<500	Works at night, is not affected by cloud cover	Requires favorable wind conditions	The Edge, Amsterdam, The Netherlands [63]
Heat Pumps	15,000/unit	Low	High efficiency (COP 3–4), year-round operation	Dependent on local geothermal conditions	Passive houses, energy-efficient buildings [64]
Gravity Power Plants	20,000+	Very low	Energy storage, grid stabilization	High construction costs, requires infrastructure	Pilot projects in urban areas [65]
Biomass	2000–4000	Medium	Uses organic waste, recycling	Emissions, requires continuous fuel supply	District heating networks in Austria and Germany [66]
Geothermal Energy	5000–8000	Low	Stable energy source, high efficiency	High initial costs, geological constraints	Reykjavik, Iceland [67]
Hybrid Systems (PV + Wind)	8000–12,000	Medium	Reduces power supply interruptions	Complex integration, high installation costs	Research stations in Antarctica [68]

7.4. Implementation Examples and Benefits

7.4.1. Bullitt Center, Seattle, DC, USA

- Costs: the investment value was approximately USD 30 million.
- Systems: photovoltaic panels have been installed, and a rainwater collection system has been implemented.
- The estimated annual energy savings are approximately USD 200,000 [59].

7.4.2. Reykjavik, Iceland

- Costs: the construction of the city's geothermal systems was estimated at approximately EUR 700 million.
- Systems: geothermal water is used to heat 90% of buildings.
- This system has been found to be significantly more cost-effective than coal-based alternatives [67].

7.4.3. District Heating Networks in Austria

- Costs: the construction of the biomass network averaged EUR 3 million per 10 km.
- Systems: biomass heating has been successfully implemented in 40 small towns.
- The benefits of this initiative are numerous; it is estimated that CO_2 emissions have been reduced by 30% [66].

7.4.4. Research Stations in Antarctica

- Costs: hybrid system installations (PV + wind) cost approximately USD 5 million.
- Systems: hybrid systems have the potential to provide energy year-round.
- This system has led to a significant reduction in fossil fuel consumption [67].

7.4.5. One Central Park, Sydney, Australia

- Costs: the total investment cost was AUD 2 billion.
- Systems: photovoltaic (PV), water recycling system, vegetation that improves the microclimate.
- The benefits that have been identified include significant energy savings and improved quality of life for residents [69].

8. The Future of Smart Cities and Sustainable Development

In the context of ongoing urbanization, the concept of "smart cities" has emerged as a pivotal aspect of 21st century urban planning.

Smart cities seek to integrate modern technologies to enhance the quality of life for residents, improve energy efficiency, and encourage sustainable development [70,71].

Songdo, South Korea, serves as a model city for the integration of advanced technologies into urban infrastructure. Songdo's adoption of advanced technologies, particularly those focused on energy and transportation management systems, has been cited as a model for reducing emissions and enhancing energy efficiency [72,73].

Another example is Masdar City, United Arab Emirates, which is fully powered by renewable energy and implements innovative solutions in transportation and waste management. These cities demonstrate how sustainable development and modern technologies can coexist, contributing to better urban living conditions [74,75].

8.1. Challenges and Barriers

While renewable energy and smart technologies offer numerous benefits, significant challenges still remain. At the same time, it is also essential to recognize the significant challenges that still remain.

First, substantial financial resources are often required to invest in renewable infrastructure, which can pose a challenge for local governments and developers. It is recommended that policies supporting green energy and financial aid systems be strengthened to help overcome these obstacles [76,77].

Integrating diverse systems and ensuring their compatibility can present technical and logistical challenges. As new technologies emerge, staff training and investment in research and development become essential to address these challenges [78].

8.2. Key Requirements of Modern Cities

The increasing demand for electricity is becoming a critical issue for the future development of cities. Urban planning that does not account for energy sources is unfeasible, as electricity is essential for daily life. Integrating gravitational energy into modern construction presents new opportunities for optimizing energy production [79].

Innovations such as photovoltaic (PV) integrated into building facades and transparent solar cells open new possibilities for designing buildings capable of self-generating energy. These technologies can reduce the dependence on municipal power grids and reduce infrastructure costs. Modern buildings, often referred to as “smart buildings”, require a constant supply of electricity [80].

Future urban planners should focus on energy self-sufficiency to ensure comfort for residents while creating educational and employment opportunities [81].

8.3. Fundamental Needs of Modern Cities

To build a modern city, several fundamental needs must be met:

- Housing Space: Urbanization has made the housing space increasingly valuable. The efficient use of the available space in densely populated cities is crucial and should include residential areas, green spaces, and public spaces [82].
- Access to Clean Water: Ensuring clean drinking water is essential for public health. Cities must invest in water infrastructure that ensures efficient delivery, purification, and conservation of water [83].
- Eco-Friendly Transportation: Developing sustainable transport systems, such as bicycles, public transportation, and car-sharing programs, is necessary to reduce congestion and emissions. Data-driven traffic management further improves transport efficiency [84].
- Recreational Areas: Green urban spaces and recreational areas are essential to improve quality of life. These spaces should cater to different age groups and social needs, ensuring inclusivity [85].
- Healthcare Services: A growing population requires well-adapted healthcare systems. Investments in hospitals, clinics, and other healthcare infrastructure are vital to providing adequate care [86].

Investments in modern energy sources and smart city technologies are essential for the sustainable development of contemporary urban areas. The future of urban planning depends on the integration of innovative solutions that improve energy efficiency and minimize environmental impact [87].

9. Discussion

The future of cities depends on energy self-sufficiency, which is both a necessity and an opportunity for sustainable development. With the increasing demand for energy and the depletion of traditional sources, effective energy management has become a critical aspect of urban development strategies. This chapter presents a critical perspective on existing solutions, with reference to the literature and real-world implementations.

9.1. Energy Self-Sufficiency

The integration of renewable energy sources (RESs) in construction projects and the use of intelligent energy management systems enable the creation of stable and adaptive energy networks. These networks can withstand weather fluctuations and unexpected power outages, enhancing their resilience to external disruptions. Cities that strive for sustainable development can therefore reduce their environmental footprint while at the same time strengthening their resilience to climate change and natural disasters [88,89].

Despite these benefits, some researchers highlight the challenges of integrating RESs into existing power grids. They emphasize the need for significant infrastructure and advances in energy storage technologies [90,91]. These challenges are in need of further research and technological innovation.

9.2. Benefits of Renewable Energy Integration

The use of modern technologies, such as transparent solar cells, is revolutionizing building design and urban planning. Buildings equipped with renewable energy systems—such as solar, wind, geothermal, and gravitational energy—can reduce CO_2 emissions by 30–50% while simultaneously lowering operating costs. Research suggests that investing in energy-efficient buildings will result in long-term financial savings, especially given the rising costs of traditional energy sources [92,93].

However, some of the literature points to the high upfront costs associated with these investments. Developers and municipalities often face financial barriers that limit the widespread availability of these technologies [94].

9.3. Testimonials

Projects like the Bullitt Center in Seattle and The Edge in Amsterdam showcase the tangible benefits of integrating renewable systems.

- The Bullitt Center has become a model for a net-zero energy office building thanks to solar panel installations and rainwater harvesting systems.
- The Edge, using intelligent energy management and renewable sources, has minimized its environmental impact [95,96].

However, these successes are not without their critics. Experts stress the need for greater standardization of such projects and the development of global regulations to facilitate their implementation in less-developed economies [97].

9.4. Challenges and Directions

Despite remarkable achievements, sustainable technology development faces several challenges. Integrating advanced technologies into urban environments requires.

- Infrastructure Investment: many cities struggle with outdated energy infrastructure, making it difficult to adopt modern solutions.
- Workforce Training: new technologies require skilled workers for installation, maintenance, and operation.
- Supportive policies for renewable energy: establishing financial incentives and regulatory frameworks is crucial for accelerating renewable energy adoption.

Sustainable urban development is not just an option, it is a necessity. Well-planned urban development, the use of modern technologies, and investment in education and scientific research will be key success factors for the cities of the future [98,99].

10. Conclusions

The advancement of technology and its integration into buildings and urban planning create new opportunities for environmental protection, improved energy efficiency, and local economic growth. In the face of climate change and urbanization, implementing sustainable strategies and investing in intelligent energy management systems has become essential.

Collaboration between the public and private sectors plays a key role in optimizing resources, accelerating the adoption of innovative technologies, and creating a shared vision for sustainable cities. Public financial support programs and regulations, combined with private initiatives in renewable energy technologies, can help reduce CO_2 emissions, lower operating costs, and increase energy independence. Examples such as the Bullitt Center in Seattle and The Edge in Amsterdam confirm that investments in green buildings not only provide environmental benefits but also increase property values and support local market development [95,96].

The results of the technologies implemented highlight the need for greater community investment in sustainable development projects. The education of residents and their active participation in decision-making processes improves the acceptance of innovations such as transparent solar cells, smart energy grids, and energy recovery systems. The transformational potential of these technologies is particularly evident in cities that effectively scale and implement these solutions to create healthier and more inclusive urban spaces [89,92].

The future of cities lies in their ability to adapt and innovate. The achievement of energy self-sufficiency and the construction of sustainable urban environments are not only a challenge, but also an opportunity to create livable spaces for the current and future generations. Urban areas that can successfully adopt modern technologies can become exemplary examples of a balance between efficiency, ecology, and quality of life [91,99].

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