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A Review on Smart Building System Integration: Optimising Energy Efficiency with the Application of Biophilic Architecture

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ABSTRACT

In an era of rapid technological development coupled with an increasing awareness of environmental sustainability concerns, implementing smart building systems has become one of the main focuses in efforts to improve energy efficiency. Biophilic architecture integrates sunlight, vegetation, and airflow to enhance human well-being. Smart building systems utilize sensor technology, automated controls, and data analysis to optimize energy use and operational efficiency. The collaboration between biophilic concepts in building design and AI technology in smart building systems is a challenging bridge connecting technology with natural elements. This research investigates how integrating these concepts can enhance energy efficiency in modern buildings while considering user comfort. The research method used is a literature analysis related to smart building systems, biophilic architecture concepts, and case studies of buildings that apply these two topics. Data was obtained from various sources including scientific journals, books, and related technical documents. The results show that the integration of smart building systems with the application of biophilic architecture concepts has great potential to improve energy efficiency while still paying attention to the comfort of its users.

1. Introduction

In this modern era, technological advances are inevitable in every aspect of life, including architecture. The integration of technology in biophilic architectural design is a major focus of architects and engineers, as it offers the potential to improve the quality, safety, and efficiency of buildings. One of the leading trends in modern architecture is the use of smart building technology. Their application not only beautifies buildings but also has a significant impact on the occupant and

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user experience by Husin [1]. Understanding the background to the integration of these technologies in biophilic architectural design is crucial.

According to research by the Department of Economic and Social Affairs, UN [2], people spend 85-90% of their time inside buildings for work, study, leisure, fun or simply living. In all cases, not only the internal but also the external environment of the building becomes important, which is directly related to the perceived and experienced quality of life. By 2050, the proportion of people living in cities is expected to increase to 68%. Smart building technology brings various benefits to users, occupants, and building owners. One of the main benefits is increased energy efficiency. Intelligent control systems enable optimization of energy use and a significant reduction in energy consumption. Smart systems also improve occupant comfort by creating a more controllable environment that suits individual preferences [1]. For example, smart building automation systems enable automatic temperature, lighting, and security settings based on occupant schedules and preferences, providing a more personalized and enjoyable experience.

Bekiaris *et al.*, [3] say concerns about climate change due to human-generated greenhouse gas emissions (such as CO2) are driving the shift to more sustainable energy systems. In many developed countries, this ambition is realized through targets set by policymakers, such as the EU 20-20-20 directive in 2020. This directive targets a 20% reduction in energy consumption by 2020 compared to 1990, along with a 20% reduction in CO2 emissions and 20% of energy generated from renewable sources.

Smart building systems utilize technology to optimize energy efficiency and occupant comfort, while biophilic architecture focuses on the relationship between humans and nature. This paper aims to explore the synergy between these two concepts. It is hoped that this integration will result in buildings that are not only energy efficient but also healthy and pleasant to live in.

1.1 Smart Building System Integration

According to Casey [4] cited by Lizar [5] smart buildings can be defined as buildings specifically designed to achieve high energy efficiency. This is made possible by the latest material and technological innovations in various fields, such as structures, equipment, electrical systems, pipes, heating, ventilation, air conditioning, and cooling systems. Hardcastle [6] in Lizar [5] also said that smart building systems have technologies that can influence the level of efficiency of daily building operations, save energy, and help reduce greenhouse gas (CO2) emissions. The principle of smart building is:

1.1.1 Automation

The Smart buildings are designed to integrate the latest technologies in managing and optimizing their internal systems. According to Ehrlich [7] this is done by combining various building systems, installing sensors to monitor building conditions, and implementing automation and data analytics. Intelligent building automation, with centralized systems and automated settings; as well as the ability to reduce energy consumption, improve efficiency, and provide a better user experience.

1.1.2 Multi-function

Multifunctional intelligent buildings are designed to maximize space and resource utilization, reduce costs, and increase occupant satisfaction, Sun [8]. Multifunctional intelligent buildings with flexible and adaptive designs can serve various user needs and increase the sustainability value of buildings.

1.1.3 Adaptability

Buckman [9] said intelligent buildings should ideally be able to learn, predict, and adapt to user needs and environmental changes. This is achieved through the integration of various aspects of the building, which enables the collection of information internally and externally from various sources. This information is then utilized to prepare the building for events that may occur before they happen. A smart building should ideally be able to adapt its operations and physical form to respond to various situations. This aims to improve energy efficiency, comfort, and occupant productivity.

1.1.4 Interactivity

Smart buildings are ideally equipped with connected systems capable of communicating with each other, as well as with their occupants, Li [10]. These systems utilize advanced sensors and intelligent controls to detect changes such as occupancy, temperature, lighting, and other factors, resulting in high interactivity. This capability enables real-time communication between the building and its occupants, ultimately improving safety, comfort, productivity, and energy efficiency for the occupants.

1.1.5 Efficiency

Multifunctional Automation systems also improve efficiency by cutting down the time required for manual adjustments. In addition, an improved occupant experience through personalized settings can have a positive impact on productivity and retention rates, ultimately resulting in cost savings. The implementation of these systems is not only limited to improving efficiency but can also create a more sustainable and comfortable environment for occupants in all types of buildings, Ejidike [11].

1.2 Energy Efficiency

The cornerstone of energy efficiency in buildings lies in optimizing energy consumption to achieve desired environmental conditions while minimizing waste. This involves a delicate balance between comfort and conservation [28][29]. According to GBCI [12] cited by Suarez [13] Sustainable energy use is becoming a major focus in modern building design, as awareness of its importance increases. Energy efficiency and conservation not only have a positive impact on the environment but also provide financial benefits and improve the comfort of building occupants. The application of energy-efficient materials and energy-saving technologies can help reduce building operational and maintenance costs, Magdalena [14]. On the other hand, proper temperature and lighting settings can improve occupant comfort, creating a healthier and more productive environment. According to Otoritas Ibu Kota Nusantara [15] here are several ways energy systems can be managed sustainably, including:

1.2.1 Renewable energy source

In nature, mechanical energy, like wind flow, is a plentiful source of sustainable and renewable energy [26]. Powering buildings with renewable energy, like sunlight with solar panels, wind with turbines, and underground heat with geothermal systems, can lessen reliance on fossil fuels and reduce harmful emissions. This makes buildings not only more eco-friendly but also more cost-effective in the long run.

1.2.2 Energy efficient HVAC system

Buildings guzzle a lot of energy, especially for heating, cooling, and fresh air (HVAC). But "smart" buildings can fight back. They use special, energy-saving HVAC systems that squeeze out every drop of efficiency and avoid wasting power. One example is smart thermostats. These clever devices can adjust the temperature based on how many people are around or how hot or cold it is outside, keeping things comfy without wasting energy. HVAC systems and artificial lighting are responsible for most of this energy demand and by minimizing this demand, a significant reduction can be made towards energy consumption [30].

1.2.3 Efficient lighting system

In smart buildings, the lights are no dummies. They have special sensors and timers that can tell when a room is empty and automatically switch off. This saves energy and keeps the lights last longer, making everyone a winner.

1.2.4 Energy storage systems

Smart sun and wind power aren't always available, but with batteries in smart buildings, that's no sweat. These energy storage systems act like piggy banks, saving extra renewable energy or grabbing some during off-peak hours. Then, when everyone needs a power boost, the batteries can unleash it, keeping things running smoothly and sustainably without straining the grid during peak times.

1.2.5 Energy management system

Smart buildings are like self-aware machines when it comes to energy. They use special systems that track, control, and fine-tune how much power they use. These systems connect to all the building's energy sources and gadgets, giving a clear picture of what's using the most juice. Then, using all this data, they recommend smart ways to cut back on energy waste and make the building run like a well-oiled machine.

1.2.6 Monitoring and analytics

Smart buildings are like detectives when it comes to energy use. They have a network of sensors and monitors that gather clues (data) about how much energy everything is used. By analyzing this data, building managers can spot areas where energy is being wasted, like a room with the lights left on all night. This real-time detective work allows them to adjust and optimize energy use, making the building run much more efficiently. One such key parameter is the building envelope which performs not only as a physical barrier between the external environment and the internal space [31] but also creates comfortable interior space by vigorously responding to the exterior condition [32].

1.3 Biophilic Architecture

According to Kellert *et al.,* [16] cited by Subroto [17] Biophilic comes from the word biophilia which is defined as an instinctive bond between humans as creatures that are responsive to natural forms. Kaffah [18] biophilic design is a design that connects nature directly in a building design that can create a restorative effect that accelerates healing in the form of improving mood and overcoming stress for users of the building. Browning *et al.,* [19] said biophilic design provides opportunities for humans to live and carry out activities in a healthy place, with minimal stress levels, and prosperous life. The design applies and connects with nature, starting from the use of materials and the form of the building design itself. Human health has a causal relationship with the indoor environment [27]. In the other hand, the quality of the air we breathe, the temperature, humidity, lighting, and other factors within our indoor spaces can significantly impact our physical and mental well-being.

According to Kellert [20] the basic human assessment of the relationship and love for nature can be known through nine fundamental aspects that represent each individual, including:

- Utilitarian: Making positive use of nature.
- Naturalistic: Making nature a source of natural diversity.
- Ecologist/Scientific: Making nature a source of science.
- Symbolic: Utilizing nature in terms of expressing and communicating the language and symbols of life.
- Aesthetic: Making the beauty of nature a universal physical attraction.
- Humanistic: Making nature a bond of "love".
- Moralistic: Making oneself ethical towards nature.
- Dominionistic: Cultivating an attitude of ownership towards nature.

The intensity of the nine fundamental aspects of biophilia should be balanced and should not cancel each other out. If one of the values of a fundamental aspect is greater, it can cause the other values to disappear.

Kellert in his book entitled Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life, cited by Justice [21] explains the application of biophilic in design, namely:

- Recurring and sustainable engagement is needed in biophilic design.
- Human adaptation to nature to promote physical and spiritual health and well-being is the focus of biophilic design.
- Biophilic design increases emotional attraction to a place.
- Biophilic design can encourage positive interactions between nature and humans to foster responsibility for nature.
- Biophilic design creates solutions in architecture that are interconnected and integrated.

1.4 Artificial Intelligence (AI)

Artificial intelligence (AI) can be defined as a set of computerized systems that perform pre-programmed tasks that are usually performed by humans [22]. Artificial intelligence can reach or exceed the intelligence possessed by humans because it can achieve the same or even more levels of perception, reasoning, interaction, and learning than humans have or do. Like humans, artificial intelligence systems can trigger changes in their own behavior without explicit reprogramming. Thus, artificial intelligence can be defined as the ability to learn from its environment and apply that knowledge to situations it has never faced.

In its application, AI can help overcome the challenges faced by humans in developing energy-efficient buildings such as by helping to increase the level of energy savings, facilitating on-site generation, detecting and minimizing various errors that commonly occur when performing conventional operations, as well as controlling and ensuring that the energy savings made are sustainable [23][24]. Therefore, adopting a digital transformation mindset when implementing AI solutions will significantly reduce operational costs while maximizing building energy performance.

2. Methodology

This research uses qualitative methods in the form of data collection through literature studies from several books, journals, government regulations, and official websites of an institution as well as comparing several studies with the same subject and function, especially on the application of smart building systems and biophilic concepts in buildings. The information obtained will provide input in planning. Deepening the analysis later by looking for comparative studies of buildings that apply smart building systems and biophilic concepts. This research aims to evaluate how the integration of smart building systems with biophilic architecture can optimize energy efficiency and improve occupant welfare. Biophilic architecture, when thoughtfully integrated, provides a holistic approach to optimizing energy efficiency in a 10-story performing arts building. It balances environmental responsibility with human needs, creating a sustainable and enriching space for artistic expression and appreciation.

3. Results

The integration of smart building systems with the application of biophilic architecture offers a holistic approach to sustainable design and provides substantial benefits in energy use efficiency and for the well-being of occupants. This section critically evaluates the benefits, challenges faced, and broader implications for sustainable development.

The Edge, a prime example of a smart building, stands tall in Amsterdam's Zuidas business district. Built in 2015, this architectural marvel by PLP Architecture and OVG Real Estate boasts over 28,000 sensors that keep a watchful eye on everything from lighting to humidity. Jalia [24] reports that this sensor network slashes energy consumption by a whopping 70 percent. The building itself is powered by the sun, thanks to more than 4,000 solar panels soaking up rays on the roof. But that's not all! The Edge is also equipped with clever systems to manage temperature, lighting, and even parking. By constantly gathering and analyzing data, The Edge operates like a well-oiled machine, optimizing its performance and setting the bar for sustainable buildings.

The Edge is designed and built to maximize the use of solar energy. The use of glass with special materials on the exterior ensures that sunlight can be used by the lighting system for a long time without affecting the interior temperature. The south side of the building is covered with solar panels that provide energy to be utilized to power the building's operations. The Edge's heating and cooling systems are controlled to last for a long duration. The pumps of the installation are equipped with solar power absorbed from sunlight. Therefore, The Edge is perfectly categorized as an environmentally friendly building. The Edge also utilizes a ventilation system and interior temperature regulation system using an intelligent ventilation system to provide a healthy environment for its users.

The Edge Building in Amsterdam is one of the most sustainable buildings in the world that uses AI assistance in its implementation. Here, AI is used to manage various operational and environmental aspects of the building. The HVAC and lighting systems are controlled automatically by AI, which utilizes data from sensors to adjust temperature and lighting based on the number of occupants and weather conditions, significantly reducing energy consumption. Facial recognition technology and real-time video analysis enhance security by identifying and managing access to specific areas within a building. Predictive maintenance is also being implemented, where AI analyzes data from equipment to detect early signs of failure and schedule repairs before problems become serious. Additionally, indoor air quality is monitored and regulated by AI to ensure a healthy and comfortable environment for residents. With this AI integration, The Edge Building has succeeded in creating an efficient, safe, and sustainable workspace, which also increases the productivity and well-being of its occupants.

Furthermore, one of the buildings that uses the application of the biophilic concept, is the Andyrahman architectural office located in Sidoarjo, East Java, Indonesia [25]. This office isn't just a place to work, it's a haven inspired by nature. Biophilic design, the philosophy behind this space, brings the outdoors in to create a healthier and happier work environment. Imagine reduced stress, a boost in energy, and a feeling of overall well-being – that's the power of biophilic design. By incorporating natural elements, this office fosters a positive impact on the team, both physically and mentally, making them feel more comfortable and leading to increased productivity and better work overall.

This ground-floor workspace is all about open design and soaking in the view of the lush green garden at its center. The garden boasts a variety of plants, from calming grasses and leafy vines climbing the walls to shrubs and shade-giving trees. These leafy friends not only create a beautiful space but also act as nature's air filters, absorbing carbon dioxide and keeping things cool. Another key feature of biophilic design – water – makes an appearance too. A central pond filled with colorful Koi fish adds a touch of serenity. The water is kept healthy with a pump that circulates it, creating a gentle gurgling sound that further enhances the natural atmosphere. Head upstairs to the second floor, and you'll find biophilic design intertwined with local traditions. The walls are adorned with woven bamboo panels, a beautiful collaboration with local artisans. These breathable walls naturally let in light and fresh air, further reducing the need for energy-guzzling air conditioning and lighting systems. So, with all these plants, water features, and open spaces, this biophilic office keeps things cool and comfortable in a way that's not only good for the environment but also minimizes energy consumption.

These two examples, show that buildings that combine smart systems and biophilic design can achieve highly efficient energy savings. This can be attributed to the following factors:

- Optimization of Heating Ventilation and Air-Conditioning (HVAC) Operations: Smart building systems can dynamically adjust heating, ventilation, and air conditioning based on real-time data about occupancy and environmental conditions, significantly reducing energy waste.
- Natural Lighting Utilization: Biophilic design maximizes the use of natural light, reducing the need for artificial lighting. Smart sensors and controls further optimize lighting based on daylight availability and occupancy.
- Enhanced Thermal Regulation: Green walls and natural materials used in biophilic architecture improve thermal insulation, reducing the load on HVAC systems. Smart thermostats ensure precise temperature control, contributing to additional energy savings.

These findings are in line with previous research, highlighting the potential of integrated systems to create more energy-efficient buildings. However, the level of energy savings may vary depending on factors such as building type, location, and the specific technology applied. The research also shows that biophilic design elements, when combined with smart building technologies, significantly improve indoor environmental quality (IEQ). These include:

- Air Quality: The presence of plants and green walls improves indoor air quality by filtering out pollutants and increasing oxygen levels. Smart ventilation systems further enhance this by ensuring optimal air exchange rates.
- Natural Lighting: Exposure to natural light has been linked to better mood and productivity. Smart systems can adjust artificial lighting to complement natural light, maintaining consistent lighting levels and reducing glare.
- Aesthetics and Psychological Benefits: Biophilic elements such as natural materials, water features, and natural landscapes create an aesthetically pleasing environment that has a positive impact on occupant well-being and satisfaction.

This improved IEQ not only contributes to occupant health and productivity but also reduces the need for energy-intensive climate control systems, creating a win-win cycle of benefits.

The integration of smart building systems with biophilic architecture produces synergistic effects that improve overall building performance including:

- Dynamic Adaptation: Smart systems can adapt in real-time to the changing conditions created by biophilic elements, such as adjusting HVAC settings based on the cooling effect of green walls.
- Optimization of Resource Use: An integrated approach optimizes the use of natural and artificial resources, ensuring energy is used efficiently without compromising comfort.
- Enhanced Resident Experience: The combination of advanced technology and natural design creates an environment that is not only energy efficient but also more pleasant and conducive to well-being.

While the benefits are clear, some challenges and limitations must be overcome to realize the full potential of this integrated approach, among others:

- Initial Costs and Complexity
  Smart system integration and biophilic design can entail significant initial costs and technical complexity. These include:
    - Capital Investment: Advanced technologies and biophilic elements require substantial initial investment, which may be a barrier for some developers and building owners.
    - Technical Integration: Ensuring seamless integration between smart systems and biophilic features can be a technical challenge, requiring expertise in both fields.
    - Maintenance and Care: Maintaining technology systems and biophilic elements can be resource-intensive, requiring ongoing investment in maintenance and upgrades.
- User Acceptance and Behavior
  The success of an integrated system also depends on user acceptance and behavior. Key issues include:
    - Occupant Engagement: For smart systems to function optimally, occupants must be engaged and willing to interact with these systems, such as using smart thermostats or lighting controls.
    - Behavioral Adaptation: Changes in occupant behavior, such as adjustment to natural light levels or plant maintenance, are essential to maximize the benefits of biophilic design.
- Long-term Performance and Scalability
  Further research is needed to assess the long-term performance and scalability of the integrated system:
    - Durability and Longevity: Evaluating the durability of biophilic elements and the longevity of smart technologies over extended periods is critical to ensure sustainable benefits.

  - Scalability: Understanding how these integrated approaches can be scaled across different building types and urban settings is critical for wider adoption.
- Future Research Directions
  To address these challenges and expand the knowledge base, future research should focus on:
  - Cost-Benefit Analysis: A detailed economic analysis to compare long-term savings and benefits against the initial investment.
  - Advanced Technology: Explores the role of emerging technologies, such as machine learning and advanced IoT devices, in improving system integration and performance.
  - Human Factors: An in-depth study of how biophilic design impacts psychological and physiological health over time, and how these benefits translate to overall productivity and well-being.
  - Policies and Standards: Develop policies and standards that support the adoption of integrated smart and biophilic building practices, ensuring that these innovations are accessible and beneficial on a wider scale live in.

4. Conclusions

The integration of smart building systems with biophilic architecture offers a promising path to optimize energy efficiency and improve occupant well-being. With the application of AI, smart buildings can become more efficient, safe, and comfortable. AI enables better resource management, predictive maintenance, and improved quality of life for residents. These concepts demonstrate the enormous potential of AI in shaping a smarter, more sustainable future of architecture and building management. Although initial costs and technical complexity present challenges, the potential benefits in terms of energy savings, improved indoor environmental quality, and occupant satisfaction make this approach a valuable strategy for sustainable urban development. Further research and development, supported by policy and economic incentives, is essential to overcome current limitations and realize the full potential of this innovative integration.

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