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The Role of AI in Enhancing the Interior Design of Sports Facilities by Applying Biophilic Design Principles

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ABSTRACT:

Sports facilities, such as arenas, stadiums, and training centers, serve as more than just venues for athletic events; they are spaces that significantly influence the well-being and performance of athletes, visitors , and spectators. The integration of artificial intelligence (AI) and Biophilic design principles into the design of sports facilities offers transformative potential for creating sustainable, functional, and aesthetically appealing interiors.

This research adopts a mixed-methods approach, combining both qualitative and quantitative analyses to examine the potential of AI in enhancing biophilic interior design in sports facilities. The research investigates the role of AI in enhancing the interior design of sports facilities by applying biophilic design principles, which emphasize the connection between humans and nature.The Results of this paper shows that the intersection of Artificial Intelligence (AI) and biophilic design principles offers exciting new possibilities for enhancing the interior design of sports facilities and also proof how AI support the integration of biophilic design elements to foster more sustainable, visually stimulating, and health-promoting environments

Finally we can admit that AI-driven tools can optimize the incorporation of natural elements, spatial arrangements, and sensory experiences to improve user well-being, energy efficiency, and environmental performance as the paper demonstrates how AI can contribute to creating spaces that improve athletic performance, mental well-being, and environmental sustainability.

Research Problem Statement :

The Application of AI technology in interior design of Sports Facility is yet under studies so this paper is studying how AI can enhance the implementation of biophilic design principles in sports facilities.

This research aims to :

Investigates the role of AI in enhancing the interior design of sports facilities by applying biophilic design principles, which emphasize the connection between humans and nature

1. Introduction

Sports facilities encompass a wide variety of building types designed to accommodate sports, fitness, recreation, and related activities. These buildings are categorized based on their structure, purpose, and usage. These facilities can range from small, local community spaces to large, state-of-the-art stadiums and arenas. They are tailored to meet the needs of athletes, spectators, and community members. The interior design of these spaces plays a crucial role in fostering comfort, focus, and motivation. The design of sports facilities involves various approaches, depending on their purpose, scale, and user needs. Biophilic design principles is one of the most necessarily design approach that should be considered in Sport Facilities as it applies the integration of Incorporating natural elements through the Use of greenery, water features, and natural materials and Maximization of natural light and ventilation and Create a connection between indoor and outdoor environments to improve well-being , sustainability and enhance the user experience. Simultaneously, advancements in AI could offer powerful tools to optimize and innovate design processes. This study investigates the intersection of these domains, focusing on how AI can enhance the implementation of biophilic design principles in sports facilities through Intelligent design assistant, data driven customization, real time environmental monitoring, enhance user experience, predictive maintenance and sustainability optimization.

2. Biophilic Design Principles

Biophilic Design Principles focus on creating environments that foster a connection between humans and nature, promoting physical and psychological well-being. These principles are often applied in architecture and interior design as shown in Fig (1) to incorporate natural elements into built environments to enhance comfort, productivity, and health .

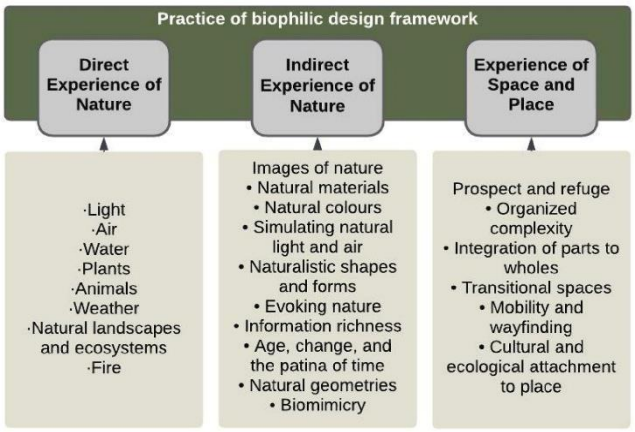

Fig. 1. Practice of biophilic design framework adapted from Kellert and Calabrese (2015).

(Bolten, B., & Barbiero, G. 2020) mentioned that It's main Key principles are to set up Visual Connection with Nature through Incorporating elements such as green walls, indoor gardens, and aquariums and adding Non-Visual Stimulations such as Using sound, scent, and texture to evoke natural experiences. Biophilic design also studies applying Dynamic and Diffuse Light like Mimicking natural lighting patterns to regulate circadian rhythms and add some Biomorphic Forms and Patterns by Integrating shapes and textures inspired by nature into design and Utilize natural materials like wood, stone, and bamboo. By applying these principles to sports facilities interior design as shown in Fig (2), it can improve cognitive function, reduce stress, and enhance

overall well-being, making them particularly valuable in high-performance environments.

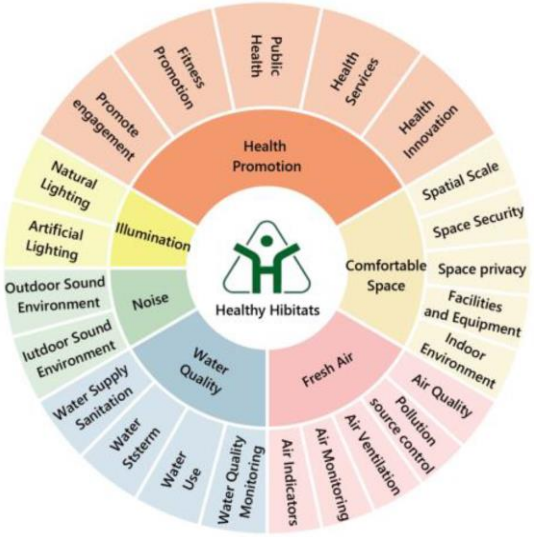

Fig. (2) shows the Intersection of Biophilic design principles in Design by researcher

3. AI Applications in Biophilic Interior Design

Artificial Intelligence (AI) is revolutionizing **biophilic interior design** by enhancing sustainability, personalization, and efficiency. One of the most significant applications is in **smart environmental control**, where AI-driven HVAC and lighting systems adjust temperature, humidity, and illumination based on occupancy patterns and circadian rhythms. AI-powered sensors also monitor indoor air quality, ensuring optimal ventilation and healthier indoor environment and with AI continuously evolving, its applications in biophilic interior design will further promote sustainability and well-being, making indoor spaces more connected to nature and enhancing human health and comfort (Adityo, Adityo.2024)..

Integrating Biophilic principles in interior design focuses on leveraging advanced technologies to create sustainable, adaptive, and nature-inspired spaces that enhance human well-being. AI can facilitate the planning, execution, and maintenance of biophilic designs in interior spaces, ensuring they are optimized for functionality, aesthetics, and ecological impact.AI technologies are reshaping the design landscape, offering capabilities such as data-driven decision-making, automation, and real-time simulation.

Furthermore, by understanding how these specific design choices influence users' reactions, AI can become a powerful tool for designers. Research by Shih-Han Hung and Chun-Yen Chang at the University of Auckland's Future Cities Research Hub sought to bridge the gap between biophilic design and user well-being while simultaneously showcasing the potential of AI. The research utilized AI to analyze landscape elements as shown in Fig (3) and then to predict the Total Environment Quality (TEQ) and related health benefits that biophilic labels (such as trees, plants, grass, and parks) could provide in comparison to urban-related labels (.Zhao, Yang & Zhan, Qinchuan & Xu, Tiancheng. 2022).

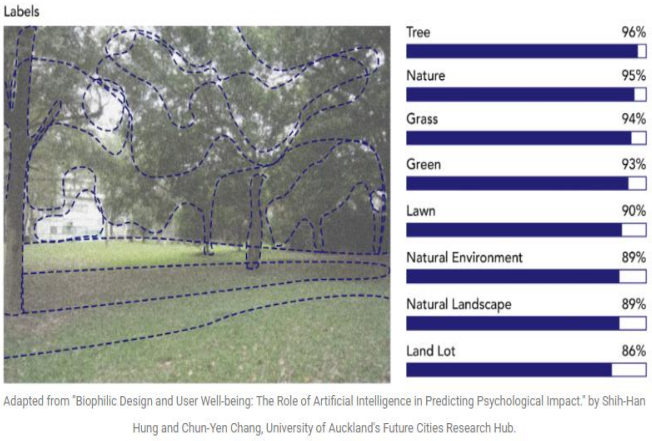

Fig. (3) Shows the Image recognition analysis in predicting biophilia through AI . (Zhao, Yang & Zhan, Qinchuan & Xu, Tiancheng. 2022).

3.1. Intelligent Design Assistance

AI-powered tools can assist architects and designers in integrating biophilic elements into sports facilities through **Generative Design** where AI algorithms can generate multiple design options that incorporate natural elements like green walls, daylight optimization, and organic layouts it suggests a wide variety of design

options that might work for a particular project. These options can then be evaluated and refined based on performance, cost, and environmental goals. And the other way by **Simulation Tools** in which AI-based simulations can predict the impact of biophilic features, such as airflow patterns for natural ventilation or how daylight affects the facility's energy consumption and aesthetic appeal, etc. and how the natural elements will contribute to the overall **aesthetic appeal** of the space. This helps architects make decisions on where to place windows or how to orient the building for optimal light use.

3.2. Data-Driven Customization

AI can analyze vast datasets to ensure that biophilic features are tailored to the specific needs of a sports facility such as **Climate Adaptation** by analyzing local climate data, AI can also recommend appropriate plant species for green roofs or vertical gardens, ensuring longevity and minimal maintenance. It also study the **User Behavior Analysis** so AI can track how athletes and spectators interact with the facility to optimize the placement of biophilic elements, such as rest areas with natural views or shaded seating areas .By considering climate and user behavior, AI helps to ensure that biophilic features aren't just aesthetic—they actively contribute to the building's **longevity, comfort, and performance**. This could mean better energy efficiency, lower maintenance costs, and happier users.

3.3 Real-Time Environmental Monitoring

AI systems can monitor and control biophilic components to maintain optimal conditions one of them is the **Dynamic Lighting Systems** where AI can adjust **artificial lighting** based on the availability of **natural light**. This helps mimic natural daylight patterns, improving **circadian rhythms** (the body's internal clock), enhancing **well-being**, and reducing **energy consumption** by using artificial lights only when needed. **Smart Irrigation** can be also AI-powered **irrigation systems** which optimize **water usage** for indoor green spaces by analyzing **weather conditions and soil moisture levels**. This ensures plants receive the right amount of water, preventing waste and maintaining healthy vegetation. AI sensors can also detect air quality and adjust ventilation or activate purifying plants to maintain a healthy indoor environment and achieve **Air Quality Control .**

3.4. Enhanced User Experience

AI technologies can make biophilic elements more engaging and beneficial for facility users **Augmented Reality (AR) Experiences**: AI-powered AR can overlay natural visuals or educational content about biophilic features, enhancing spectator and athlete experience immersive **nature-based visuals** to improve their connection with the space and their interaction with the environment. **Personalized Recommendations** through AI can also provide users with customized routes or zones within the facility like **quiet garden area** that promote relaxation or focus, or a **pathway lined with greenery** to help users de-stress.

3.5. Predictive Maintenance

AI-driven maintenance systems ensure the longevity of biophilic features like **Monitoring green elements Health** AI can use image recognition to identify plant diseases or pests in green walls or gardens and suggest treatments and include also **IoT Sensors** Embedded to measure **moisture, temperature, and light levels**, ensuring proper care. It also works in It also helps preserve **natural materials** like wood, stone, and moss walls by detecting humidity, temperature fluctuations, and structural wear. AI-controlled **water management** optimizes indoor irrigation and prevents leaks in water features, while **air quality sensors** adjust ventilation and climate conditions to support both human comfort and plant vitality. By predicting maintenance needs early, AI reduces repair costs, extends the lifespan

of biophilic elements, and creates healthier, more sustainable indoor environments.

3.6. Sustainability Optimization

AI plays a crucial role in optimizing **sustainability** within **biophilic interior design** by enhancing energy efficiency, reducing waste, and maximizing environmental benefits. AI-driven **energy management systems** can regulate **natural light, temperature, and ventilation** by adjusting window shading, green facades, and strategically placed vegetation to reduce reliance on artificial lighting and HVAC systems. Through **waste tracking and predictive analytics**, AI minimizes material waste during **construction, installation, and maintenance** of biophilic elements by optimizing resource allocation and suggesting **eco-friendly alternatives**. Additionally, AI can assess and **enhance carbon sequestration** by analyzing the potential of **indoor plants, green walls, and natural materials** to absorb CO_2, recommending design adjustments for **maximum environmental impact**. By integrating AI into biophilic spaces, facilities can achieve their **sustainability goals**, reducing their carbon footprint while maintaining **healthier and more efficient indoor environments**.

3.7. Crowd and Space Management

AI enhances **crowd and space management** in **biophilic sports facilities** by ensuring that **green spaces and natural elements remain functional, comfortable, and sustainable** in high-traffic areas. Through **dynamic layouts**, AI analyzes **real-time foot traffic and spectator movement** to adjust **seating arrangements, athlete pathways, and entry/exit routes**, preventing congestion and preserving **green walls, indoor gardens, and relaxation zones** for athletes and visitors. AI-driven **spatial optimization systems** can suggest **flexible seating zones, nature-integrated rest areas, and adaptive circulation pathways** that balance **spectator flow with biophilic elements**, enhancing both functionality and aesthetics. Additionally, AI-powered **acoustic management systems** can integrate **natural soundscapes**, such as **water features or plant-based noise barriers**, to **reduce stadium echoes and external noise pollution**, creating a more **immersive and calming environment** for athletes and fans. By using AI to **optimize crowd movement, spatial organization, and acoustic comfort**, biophilic sports facilities promote **well-being, performance, and sustainability**, ensuring an enhanced experience for players and spectators alike.

3.8. Long-Term Impact Assessment

AI can significantly enhance the long-term benefits of biophilic design in sports facilities by tracking various metrics and optimizing design elements. It can assess the physiological and psychological impact of biophilic features on athletes and spectators, such as measuring stress reduction, improved focus, and overall well-being. Through continuous monitoring, AI can also provide insights into the cost-effectiveness of these designs by tracking energy and water usage, demonstrating the environmental and financial benefits of biophilic integration. Additionally, AI can analyze community engagement, using feedback to refine and suggest improvements to the facility's biophilic elements. **Generative design** algorithms can create multiple layout options based on biophilic principles, like maximizing natural light exposure or strategically placing vegetation. AI can also analyze environmental factors like air quality and light conditions to suggest design adjustments that enhance the user experience. By interpreting user preferences through machine learning models, AI can personalize design elements, such as seating arrangements or lighting conditions. Furthermore, AI can support predictive maintenance, monitoring and maintaining biophilic features like irrigation systems for plants or dynamic lighting setups, ensuring sustainability and functionality in sports facilities.AI can track the

long-term benefits of biophilic design in sports facilities:

4. Case Study : Mercedes-Benz Stadium in Atlanta

The integration of AI and biophilic design in sports facilities is illustrated through several case studies some Modern sports facilities, such as Mercedes-Benz Stadium in Atlanta, integrate AI with biophilic principles. The stadium features rainwater collection, solar panels, and AI-driven energy management systems to optimize energy consumption. Other smart stadiums use IoT and AI to control lighting and ventilation based on occupancy and weather conditions, reducing their carbon footprint as shown in Image (1) below .

Mercedes-Benz Stadium in Atlanta exemplifies the integration of artificial intelligence (AI) and biophilic design principles in sports facilities. The stadium features 4,000 solar photovoltaic panels, producing approximately 1.6 million kilowatt-hours of renewable energy annually, which is enough to power multiple games or 160 households in Atlanta. This renewable energy generation reduces greenhouse gas emissions and contributes to the local electrical grid.

a) b)

Image (1) : Shows the transformation of roof by the use of IoT and AI to control lighting (Mercedes Benz 2024)

In terms of water conservation, the stadium has implemented a 2.1 million-gallon stormwater management system comprising bioswales, a cistern, and a stormwater vault. The 680,000-gallon cistern harvests rainwater used for irrigating the exterior landscape and cooling towers, while the underground stormwater vault captures and slowly releases stormwater to help prevent flooding in neighboring communities.

Furthermore, the integration of AI in building management systems enables real-time adjustments to optimize energy use, contributing to significant reductions in energy consumption and carbon emissions. These advancements highlight the potential of combining AI with biophilic design to create sustainable, energy-efficient, and user-friendly sports facilities.

5. Challenges and Limitations

While promising, AI-driven biophilic design faces several challenges. AI-driven biophilic design in the interior design of sports facilities offers significant potential, but also faces several challenges. One major hurdle is the high cost of implementing advanced AI systems and biophilic elements like living walls, natural materials, and dynamic lighting. These features, while beneficial for creating a healthy and engaging atmosphere, can significantly increase both construction and maintenance costs. Moreover, integrating AI solutions with the architectural and engineering constraints of sports facilities can be complex, requiring collaboration between interior designers, architects, and technology experts to ensure seamless functionality and aesthetic cohesion. The collection of user data and environmental information, while essential for optimizing AI-driven systems, also raises privacy concerns, especially in spaces where large crowds gather. Additionally, ethical considerations must be addressed, particularly in maintaining the balance between technological interventions and the authenticity of biophilic design. It’s crucial to ensure that the use of AI does not overshadow the natural, human-centered qualities that biophilic design aims to foster within the interiors of sports venues.

6. Benefits of AI-Enhanced Biophilic Design in Sports Facilities

6.1. Enhanced Athlete Performance: Biophilic design elements, such as natural light, plants, and water features, have been shown to reduce stress and improve cognitive function, which can be beneficial for athletes. In sports facilities, incorporating these elements can help athletes maintain focus, recover from physical exertion, and improve mental clarity. For instance, the presence of greenery has been linked to decreased anxiety and better mood regulation, which directly translates to improved concentration and performance on the field. AI can further enhance this by creating a dynamic environment tailored to individual athlete needs, adjusting lighting, temperature, and air quality to promote optimal performance conditions.

6.2. Improved Spectator Experience: For spectators, biophilic design creates an immersive and enjoyable environment that enhances the overall experience of attending a sporting event. Incorporating natural elements, such as green spaces, water features, and views of the outdoors, helps to create a relaxing atmosphere and reduces feelings of crowd-related stress. AI can optimize this experience by adjusting lighting and temperature based on the time of day, weather conditions, or crowd density, ensuring comfort throughout the event. Additionally, AI can analyze audience feedback in real time to identify areas for improvement, making it possible to tailor the environment to enhance engagement and satisfaction.

6.3.Sustainability:
AI can play a pivotal role in improving the sustainability of sports facilities by optimizing resource usage. For example, AI-driven systems can monitor and manage energy consumption, lighting, and heating in real time, adjusting settings based on occupancy and environmental conditions, which reduces waste and energy costs. Water usage can also be optimized by using AI to control irrigation systems for biophilic elements, ensuring plants are watered only when necessary and minimizing water waste. Additionally, AI can track the performance of sustainable technologies, such as solar panels or rainwater collection systems, ensuring they operate efficiently and in line with green building standards like LEED certification.

6.4.Adaptability:
One of the key benefits of AI-enhanced biophilic design is its adaptability. AI systems can continuously learn from environmental data, such as weather conditions, crowd size, and user preferences, and adjust the built environment accordingly. For example, lighting systems can adjust to natural daylight levels, HVAC systems can optimize airflow based on occupancy, and plants can be monitored to ensure they are thriving in their environment. In sports facilities, this adaptability can be especially valuable as it allows spaces to be transformed to accommodate different types of events or activities, providing flexibility while maintaining the health-promoting benefits of biophilic design. AI can also enable real-time adjustments to improve comfort and user experience, ensuring the facility is always optimized for both athletes and spectators.

7. Future Directions Research in AI and biophilic design should focus on:

- Developing cost-effective AI solutions tailored to sports facilities.
- Enhancing interdisciplinary collaboration between designers, technologists, and sports professionals.
- Exploring the long-term impact of AI-enhanced biophilic design on user well-being and performance.
- Advancing AI-driven sustainability practices within the biophilic framework.

8.The Future of Sports Facility Design

The future of sports facility design is set to be shaped by ongoing technological innovations and a strong focus on sustainability and inclusivity.

Emerging trends like artificial intelligence (AI), blockchain technology for ticketing and security, and the incorporation of cutting-edge materials such as graphene will play a pivotal role in transforming sports venues. The emphasis will be on developing smart, sustainable, and versatile facilities that deliver exceptional experiences for all users.

9.Conclusion

AI has the potential to revolutionize the application of biophilic design principles in sports facilities, creating spaces that promote well-being, performance, and sustainability. By addressing current challenges and fostering innovation, stakeholders can harness the synergy between AI and biophilic design to redefine the interior design of sports facilities for the future.

10. Results

Artificial intelligence (AI) can enable biophilic design to adapt and respond to user needs and preferences, creating a personalized and dynamic environment. AI is used to analyze biometric data, of players inside the sport facility such as heart rate, blood pressure, or mood, and adjust the biophilic elements accordingly. For example, AI can change the color, intensity, or direction of the light, the type or volume of the sound, or the fragrance or humidity of the air, to create the optimal conditions for your comfort and health.

This results could be implemented as follows
1- Integration of Biometric Sensors
Install wearable or non-invasive sensors to monitor players' real-time biometric data, such as heart rate, blood pressure, body temperature, and emotional state. These sensors serve as the data source for the AI system to analyze physiological and psychological conditions.

2- Development of a Smart Environmental Control System
Create an AI-driven control system connected to environmental components such as lighting, ventilation, sound systems, and fragrance diffusers. The system should use biometric inputs to make real-time adjustments tailored to individual or group needs.

3- Use of Adaptive Biophilic Design Elements
Incorporate dynamic design features—like color-changing LED lights, adjustable natural soundscapes, smart ventilation for air quality, and automated water features—that can be controlled through AI to simulate natural environments and promote well-being.

4- Customization Algorithms Based on User Profiles
Develop machine learning algorithms that learn from users' historical data and preferences to offer personalized environmental settings. This ensures continuous adaptation and improvement in comfort and performance enhancement.

5- User Feedback and Continuous Learning
Implement a feedback system where users can manually input their comfort levels or preferences, allowing the AI to refine its responses over time. This feedback loop supports more accurate personalization and long-term system effectiveness.

6- Pilot Testing in Real Sports Facilities
Conduct pilot studies in selected sports facilities to test the AI-biophilic system's impact on player performance, mental health, and recovery. Use the data to refine system algorithms and prove the concept's effectiveness.

7- Collaboration with Design and Tech Experts
Work with architects, interior designers, AI developers, and health professionals to create an interdisciplinary framework that ensures both the technological and aesthetic quality of the biophilic system.

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