JPSTD
Journal of Placemaking and Streetscape Design
JPSTD 3(2): 113–128
ISSN 3025-5449

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

Green transformation of airport architecture through biophilic design: A comparative study of Changi, Munich, and Banyuwangi

Isdanto Rahusodo[1,*]

[1] *Department Architecture, Faculty of Engineering, Universitas 17 Agustus 1945, Semarang, Central Java 50233, Indonesia.*

*Correspondence: isdanto.rahusodo@gmail.com

Received Date: November 13, 2025 Revised Date: January 18, 2026 Accepted Date: January 26, 2026

ABSTRACT

Background: Modern airports play a vital role in the global transportation network, but they also contribute greatly to the environmental crisis due to high energy consumption and carbon emissions. This study examines the transformation of green architecture through the application of biophilic design as a mitigation strategy at three international airports (Changi, Munich, and Banyuwangi). **Methods:** A comparative case study approach with mixed methods (architectural observation, document analysis, and user surveys) was used to evaluate the integration of biophilic elements in an effort to improve energy efficiency, resource management, and adaptation to local climatic and cultural conditions. **Findings:** The results of the study show that the adaptation of biophilic design that takes into account local wisdom and local climate is able to optimize the performance of the airport environment, significantly reduce energy consumption and carbon emissions, and improve the psychological comfort of users. In addition, the application of natural elements such as indoor gardens, artificial waterfalls, green roofs, and natural ventilation is proven to create a healthier and more attractive space atmosphere. **Conclusion:** These findings enrich the discourse on sustainable architecture, affirm the relevance of biophilic design in facing the challenges of the global environmental crisis, and provide practical recommendations for the development of more environmentally friendly transportation infrastructure. **Novelty/Originality of this article:** This study offers originality by demonstrating how biophilic design, grounded in local wisdom and climatic context, can transform large-scale airport infrastructure into sustainable, human-centered public spaces with strong cultural identity, while simultaneously enhancing ecological performance and user well-being.

Keywords: airports; biophilic design; energy efficiency; sustainability; sustainable architecture

1. Introduction

Airports serve as vital nodes in global transportation networks, supporting the movement of people and goods between countries. According to the International Air Transport Association (IATA, 2023), airports around the world manage more than 4.5 billion passengers annually and account for around 4.1% of the global Gross Domestic Product (GDP). As an important infrastructure in the world economy, the airport not only serves as a transit point, but also becomes a hub of activity that connects the international trade, tourism, and business sectors (Florido-Benítez, 2022; Franciscone et al., 2024; Kanyio et al., 2023).

Cite This Article:
Rahusodo, I. (2026). Green transformation of airport architecture through biophilic design: A comparative study of Changi, Munich, and Banyuwangi. *Journal of Placemaking and Streetscape Design, 3*(2), 113–128. https://doi.org/10.61511/jpstd.v3i2.2026.2440

With the increasing demand for air transportation, the airport industry is experiencing rapid growth, which is driving capacity expansion and the construction of new terminals (Airports Council International, 2022; Zhang & Graham, 2020). However, this expansion also presents serious challenges, especially related to environmental impacts. The airport's operational activities result in very high energy consumption, greenhouse gas emissions, and the use of materials that are not environmentally friendly (Schlenker & Walker, 2016). Modern airports consume even more energy than ordinary commercial buildings, especially for fossil fuel-fueled air conditioning, lighting, and transportation systems.

The environmental challenges facing airports are driving the adoption of sustainable solutions, such as efficient design in energy use and more prudent management of resources (Khanna & Swami, 2025; Sreenath et al., 2021). One of the approaches that is now widely applied is biophilic design. Biophilic design is an approach that integrates natural elements into built-up spaces with the aim of improving the quality of life of residents and reducing the ecological impact generated by buildings (Kellert, 2008). The integration of natural elements such as natural lighting, vegetation, natural ventilation, and water is key in creating a healthy and comfortable environment.

In the context of airports, the application of biophilic design brings many benefits, such as energy savings through natural lighting, cross-ventilation, reduction of noise pollution, improvement of indoor air quality, and improvement of thermal comfort (Browning et al., 2014). Elements such as indoor gardens, artificial waterfalls, and green waiting rooms play a role in creating a calming atmosphere, reducing stress, and improving the atmosphere of the space (Ryan et al., 2014).

Research by Han et al. (2020) also shows that the implementation of sustainable design strategies can improve energy efficiency and improve the image and welfare of airport users. On the other hand, a report from Changi Airport Group (2020) proves that the implementation of green initiatives such as green roofs, rainwater recycling systems, and natural lighting at Changi Airport not only reduces the carbon footprint, but also improves the quality of public spaces.

This study aims to examine and compare the application of biophilic-based sustainable architectural design in three international airports, namely Changi Airport in Singapore, Munich Airport in Germany, and Banyuwangi Airport in Indonesia. These three airports were chosen because they are considered representative in the application of sustainability and biophilic principles, and have different geographical, cultural, and environmental policy backgrounds. This study addresses several key aspects. First, it examines how the principles of biophilic design are applied in the three airports within their respective contexts. Second, it analyzes the sustainable design strategies implemented and the local challenges encountered by each airport. Third, it evaluates the impact of biophilic design implementation on energy efficiency, resource management, and environmental quality. By comparing cases in three different locations, this study is expected to enrich the literature on the application of biophilic design to large transportation infrastructure, while providing practical insights for airport managers, architects, and policymakers.

1.1 Theoretical review of biophilic design and sustainability in airport environment

Sustainable architecture aims to minimize the negative impact of buildings on the environment through energy efficiency, the use of environmentally friendly materials, and the wise management of resources (Newman & Kenworthy, 2015). In the context of airports, the main challenges lie in the high energy requirements for terminal operations, the large use of fossil energy for air transportation, and the often high lighting requirements (Gössling & Upham, 2009).

The implementation of sustainable architecture at the airport requires an efficient energy management strategy, considering that the airport's energy consumption is huge for cooling, lighting, and technological operations (El Zein et al., 2025; Yildiz et al., 2022). For example, London's Heathrow Airport consumes more than 300 million kWh of energy per year, mostly for cooling and lighting systems (Gössling & Upham, 2009). To address these challenges, many international airports are starting to adopt green technologies such as solar panels and smart energy management systems to reduce dependence on fossil energy (Wired, 2008). In addition, sustainable design also involves the use of environmentally friendly materials, waste management, and the implementation of energy recovery systems. Munich Airport in Germany, for example, has successfully implemented green roofs and energy recovery systems that are effective in improving energy efficiency while reducing environmental impact (Flughafen München GmbH, 2018).

1.2 Principles of biophilic design in modern architecture

Biophilic design is an approach that integrates natural elements into a built space to improve the quality of life and well-being of its occupants. The concept of biophilia, introduced by (Wilson, 1984), argues that humans have a natural interest in nature and living ecosystems. Biophilic design principles include natural elements such as plants, fresh air, natural light, as well as the use of materials that mimic natural shapes and patterns, all of which contribute to improving the quality of the built environment (Kellert, 2008).

Browning et al. (2014) divide biophilic design into three main categories, direct connection with nature: integration of direct natural elements, such as indoor gardens, waterfalls, and natural lighting, indirect connections: the use of natural materials, textures, and forms of biomimicry that mimic nature, space and place experiences: space designs that create a feeling of closeness to nature, giving a sense of "retreat" or a calming place. Research by Kellert (2018) shows that natural elements in buildings can improve mental health, reduce stress, and improve users' sleep quality. This concept is particularly relevant for the airport environment, which is often a crowded and stressful public space. With the application of biophilic design, the airport can create a more positive and comfortable experience for its users.

The application of biophilic design in Airport architecture has been implemented in several international airports, with results varying depending on the local context and the policies of each airport (Anastya & Aletta, 2025; Ariff et al., 2025). Changi Airport in Singapore is a prime example of the application of biophilic design in Airport infrastructure. One of its iconic projects is Jewel Changi, which features the Forest Valley, a sprawling indoor tropical park, as well as the Rain Vortex, the world's tallest indoor waterfall. The project aims to create a calming atmosphere for Airport users by providing ample green spaces, as well as reducing reliance on artificial cooling systems through natural ventilation and passive lighting. By combining green technology and biophilic design, the project successfully creates an environmentally friendly and user-friendly environment (Ghrab, A., & Feiz, 2025; Tabassum & Park, 2024).

Munich Airport in Germany adopts a sustainable design with a focus on energy efficiency and resource management. One of the key innovations is the use of green roofs that help reduce the impact of local warming as well as provide green open space for Airport users. In addition, the airport also implements an energy recovery system to reduce energy consumption from cooling and lighting systems. Although the natural elements in the interior design are limited, the airport utilizes green technology to achieve high sustainability goals (Bamidele et al., 2023; Santa et al., 2020). Banyuwangi Airport in Indonesia is an example of the application of passive tropical design by utilizing local materials such as bamboo and wood to reduce energy consumption and support sustainability. This design includes the use of natural cross ventilation and natural lighting to minimize reliance on artificial lighting. The airport stands out for its design that prioritizes local wisdom and adaptation to Indonesia's tropical climate, which shows that biophilic design can be adapted to the local climate and cultural context (Andra Matin Architect, 2018; Ministry of Transportation of the Republic of Indonesia, 2020)

Based on a literature review on sustainable architecture and biophilic design in the airport environment, there are several gaps identified. Previous studies have extensively discussed the application of sustainable design in general at airports and the positive effects of biophilic design in public buildings. However, research that specifically compares the integration of biophilic designs based on different geographic and cultural contexts at international airports is still very limited. In addition, there has not been much research that comprehensively links the application of biophilic design with energy performance measurement and carbon emission reduction in the airport environment. Therefore, this study aims to fill the gap by comparing the application of biophilic design in three different airports (Changi, Munich, and Banyuwangi) based on biophilic elements, climate context, local culture, and its impact on operational sustainability.

2. Methods

2.1 Research approach and design

This study uses a mixed methods approach, which combines exploratory qualitative and quantitative descriptive methods in one integrated analysis framework. This approach was chosen to provide a comprehensive understanding of the application of biophilic design in three international airports, both in terms of the architectural strategy applied and from the perspective of the user as a spatial actor. The strategy used is *a* concurrent embedded strategy (Creswell & Clark, 2018), where qualitative data plays the role of the main source, while quantitative data is used as a complement and verification of the observed spatial phenomena. The object of this research is the elements of biophilic design applied to three international airports, namely Changi Airport, Singapore, Munich Airport, Germany, and Banyuwangi Airport (Indonesia).

Location coordinates of Changi Airtport, 1.3644° N, 103.9915° E. The Northern Boundary is located in the northeastern part of Singapore, with the northern boundary being about 1.4° N, near Pasir Ris. The Eastern Boundary faces directly the Straits of Johor and the state of Johor. The Southern Boundary faces the South China Sea, its southern boundary is about 1.3° N. The Western Boundary, close to the Bedok and Tampines regions, the western boundary is about 103.9° E. Location coordinates of Munich Airport, 48.3538° N, 11.7861° E, Munich Airport is located north of Munich, in the Freising area, with a northern boundary of about 48.5° N. Eastern Boundary, Close to the city of Erding, its eastern boundary is about 11.9° E. Southern Boundary, Leads to the area around Ismaning, with a southern boundary of about 48.2° N. Western Boundary, Located close to the city of Garching, with a western boundary of about 11.6° E.

And the last the location coordinates of Banyuwangi Airport, 8.1717° S, 114.3320° E. The North Boundary, located in Banyuwangi Regency, with a northern boundary of about 8.1° S, towards the coastal area. The Eastern Boundary, facing the Bali Sea and the Bali Strait, the eastern boundary is about 114.35° E. The Southern Boundary, leading to the Indian Ocean sea, the southern boundary is about 8.3° S. The Western Boundary, located closer to the Glenmore and Sukamade regions, the western boundary is about 8.0° S.

The selection of locations was purposively based on the representation of the three airports towards the desired approach and biophilic design, as well as different geographical, cultural, and climatic backgrounds. The subjects of the quantitative research consisted of airport users (passengers) who had direct experience at one of the three airports, with a total of 9 respondents who were purposively selected through an online survey. This limited sample size is due to limited access to respondents and the focus of research that is exploratory, so it does not aim for statistical generalization.

2.2 Data collection techniques

The data in this study consist of both qualitative and quantitative data. Qualitative data were collected through several approaches. First, a document review was conducted on architectural documents, master plans, design publications, and sustainability reports published by airports and relevant architectural institutions. Second, spatial visual observations were carried out based on photographs, videos, and official documentation to identify biophilic attributes within the airport environment, such as indoor gardens, natural lighting, cross ventilation, water elements, and the use of natural forms and materials.

Meanwhile, quantitative data were obtained through an online questionnaire using a Likert scale (1–5), consisting of 15 statement items. The instrument was designed to measure user perceptions regarding several key aspects, including the quality of the airport environment, spatial comfort, and user preferences toward the design. The items in the questionnaire were compiled based on 14 biophilic design patterns (Browning et al., 2014) and theories from (Kellert, 2008, 2018), and have been validated in terms of content through previous literature review.

Table 1. Data types and purposes of use

Data Type	Data Source	Intended Use
Visual observation	Spatial documentation and airport photos	Identify the application of biophilic elements such as gardens, natural light, ventilation, water, and materials
Design documents	Masterplan, architecture publications, sustainability reports	Understand the architectural strategy and sustainability approach at each airport
User questionnaire	Online survey to airport users	Measuring the perception of comfort and the impression of sustainability in airport public spaces
Literature akademik	Theoretical studies of biophilic design and sustainable architecture	Compile indicators and validate questionnaire content and support data triangulation
Contextual spatial data	Local geographical location, climate, and cultural background	Analyze design adaptations to local challenges such as tropical climate, low temperatures, or urban density

2.3 Data analysis techniques

The data analysis in this study consisted of qualitative and quantitative approaches. Qualitative data were analyzed using thematic–comparative analysis with the assistance of NVivo 12 software to identify the main themes emerging from visual observations and architectural documents. The analysis process involved coding the data, mapping patterns of findings, and evaluating the suitability of biophilic design applications within the local context, including climate conditions, cultural aspects, and regulatory frameworks. Meanwhile, quantitative data were analyzed using descriptive statistical methods with the assistance of SPSS software version 25. The analysis included the calculation of mean values, modes (most frequent values), and the frequency distribution of respondents' answers for each questionnaire item. Inferential statistical tests were not applied because the research was exploratory in nature and involved a relatively small sample size.

The mixed method approach applied in this study, with the integration of thematic analysis using NVivo and descriptive statistical analysis through SPSS, allows the creation of comprehensive data triangulation. This combination not only strengthens the validity of the findings, but also provides a deeper and more thorough understanding of the effectiveness of biophilic design applications in supporting sustainable architecture in airport environments. Thus, this methodology is expected to make a significant contribution to the development of green and biophilic architecture studies at the scale of global transportation infrastructure.

3. Results and Discussion

3.1 User perception summary

As a first step, user perceptions were analyzed through a Likert scale questionnaire (1–5) filled out by 9 respondents who had direct experience at one of the three case study airports (Changi, Munich, and Banyuwangi). The questionnaire consists of 15 statement items that evaluate various biophilic variables, such as vegetation, water elements, natural lighting, ventilation, natural materials, cultural identity, spatial navigation, psychological comfort, sustainability, and public support.

The results of the questionnaire showed that the majority of variables obtained high average scores, indicating positive acceptance of biophilic designs. The variable with the highest average score was public support (4.89), followed by vegetation (4.78) and air circulation (4.78). Cultural identity obtained a lower average score (4.44), indicating the need to strengthen local cultural aspects in airport design.

3.2 Quantitative analysis (SPSS)

Quantitative analysis was conducted with 9 respondents, using SPSS version 25 to calculate the mean value, mode, and frequency distribution. Table 2 below summarizes the results of quantitative analysis of user perceptions of biophilic elements at the case study airport. This table presents the mean, mode, and number of respondents who gave the highest rating ("Strongly Agree" or a score of 5) on each variable. This presentation shows a very positive level of acceptance of biophilic design, especially in terms of vegetation, comfort, and public support for sustainability.

Table 2. Summary of Results of Quantitative Analysis of User Perception (SPSS, n = 9)

Variabel	Mean	Mode	# They respond "Strongly agree" (5 of 9)
Presence of vegetation	4.78	5	7
Natural sunlight	4.67	5	6
Water element (pool/fountain)	4.56	5	5
Natural material	4.56	5	6
Natural colors/patterns	4.56	5	6
Lounge comfort	4.78	5	7
Space navigation	4.67	5	6
Quiet and quiet space	4.44	5	5
Energy saving	4.67	5	6
Support for green design	4.89	5	8
Hopes for other airport's biophilic adoption	4.89	5	8
Fresh air circulation	4.78	5	7
Local cultural identity	4.44	5	5

Based on Table 2, it can be seen that most of the respondents gave high scores on almost all variables. Support for green design and the expectation for biophilic concepts to be adopted at other airports obtained the highest scores, with a mean of 4.89 and 8 respondents voting "Strongly Agree" respectively. This confirms that the public has a high awareness of the importance of sustainability and environmental quality of airport public spaces. Meanwhile, the cultural identity variable still showed room for improvement, reflected in a lower average score (4.44) and only 5 respondents voted "Strongly Agree". These findings indicate the need for efforts to strengthen local expression in the application of biophilic design to further enrich the user experience 4.89.

3.3 Qualitative analysis (NVivo)

Qualitative analysis was carried out using NVivo 12 on open answers and architectural documents. The *coding* process produced five dominant themes that describe user perceptions of the application of biophilic design at airports, namely (i) The presence of natural elements (plants, water) as a factor of visual calmness, (ii) The comfort of the waiting room as *a healing space*, (iii) Intuitive and effective spatial navigation, (iv) An eco-friendly image that enhances user pride, (v) Local cultural identity as a distinguishing element, although it still needs to be strengthened. These findings are summarized in Table 3 below.

Table 3. Summary of qualitative analysis themes (NVivo) on user perception

Main Theme	Description	Representative Quotes
The presence of natural elements	The vegetation and water elements provide visual tranquility and comfort.	"Lots of greenery, soothing natural lighting."
Healing space & comfort	The waiting area is spacious and comfortable, helping to reduce stress.	"The waiting room is very comfortable, it makes you feel at home."
Intuitive space navigation	Paths and directions are easy to follow, making orientation easier.	"It's easy to find the gate, the flow of the space is clear."
Environmentally friendly image	The design supports green branding and promotes pride.	"The airport is modern and very supportive of environmental awareness."
Cultural identity	Local materials and cultural elements are starting to be felt, but they are still not strong.	"The design is good, but the local culture is not yet very felt."

This table shows the integration between visual function, psychological comfort, green imagery, and local cultural values. Although it is generally positively appreciated, the theme of cultural identity is an important opportunity to be improved in the application of biophilics in the local context of Indonesia and other global airports. Other examples of narrative quotes support these findings, such as:

> *"The waiting room is very comfortable, lots of greenery, soothing natural lighting."* (Respondent A)

> *"The concept of the airport really supports environmental awareness, hopefully many other airports will follow."* (Respondent B)

3.4 Integrated discussion

This study grouped the results and discussion into five main themes, by integrating qualitative (NVivo thematic analysis) and quantitative (SPSS descriptive analysis) data. Each theme is studied in depth to explore the contribution of novelty in the context of the application of biophilic design in airport architecture. The observation results showed that Changi Airport utilizes a large-scale indoor park (Forest Valley) and the iconic waterfall (Rain Vortex) as the main elements that support the visual and psychological comfort of users. Munich Airport integrates a green roof that helps heat absorption and improves the thermal performance of the building. Meanwhile, Banyuwangi Airport makes adaptive use of local vegetation in the circulation area and waiting room. The results of the questionnaire supported this finding, with an average score of 4.78 for the perception of the presence of vegetation and 4.56 for water elements. The elements of nature have been shown to not only enhance the aesthetics of the space, but also serve as a stress reducer, in line with the theories of biophilia by Wilson (1984) and Kellert (2008). This study emphasizes that vegetation and water elements serve as psychological landmarks that reinforce the identity of airports, as well as innovative strategies for energy efficiency, expanding the role of biophilics in the realm of transportation architecture.

Table 4 shows the comparative details of the application of vegetation and water elements in the three case study airports, along with the design strategies and psychological functions that resulted. Scores marked with an asterisk (*) represent evaluative ratings generated through qualitative analysis and expert judgment, reflecting the integration and effectiveness of vegetation and water elements, as well as their psychological and environmental impacts in each airport case study. Changi stands out as a global psychological landmark icon with its largest indoor park and waterfall. Munich optimizes green roofs as thermal insulation, while Banyuwangi utilizes local vegetation as part of tropical adaptation. This shows that the integration of vegetation and water not only beautifies spaces, but also supports energy efficiency and creates a calming emotional experience.

Table 4. The presence of natural elements at airport case study (final)

Airport	Vegetation Elements	Water Element	Design Strategy	Vegetation Score	Water Score	Psychological & Energy Function
Changi	Large-scale indoor park (Forest Valley), tropical vertical vegetation.	Indoor waterfall (Rain Vortex).	Indoor landscape + landmark iconic.	4.78	4.56	Creates a relaxing atmosphere, psychological landmarks, improves air quality & cooling.
Munich	Green roof, semi-open roof garden.	Small reflective pool in the outdoor plaza.	Green roof + hybrid courtyard.	4.00*	4.00*	Improve thermal performance, add green areas, reduce urban heat islands.
Banyuwangi	Local vegetation in semi-outdoor circulation spaces, tropical landscapes.	Entrance & transition water pool.	Local tropical adaptations are open.	4.50*	4.20*	Provides freshness, strengthens local identity, supports natural ventilation.

3.5 *Natural lighting and ventilation: Contextual energy efficiency*

Natural lighting is applied through skylights and glass façades in Changi and Munich, while Banyuwangi features tropical cross ventilation that utilizes natural winds. This supports energy efficiency while creating thermal comfort. The questionnaire score showed a high appreciation of natural lighting (4.22) and air circulation (4.56). This study expands on the concept of energy efficiency (Newman & Kenworthy, 2015) by proving the integration of tropical cross-ventilation as an adaptive solution that supports psychological comfort and sustainability.

Table 5. Lighting and ventilation strategy at airport case study

Airport	Natural Lighting Strategy	Ventilation Strategy	Lighting Score	Ventilation Score	Psychological, Thermal, Energy & Environmental Functions
Changi	Large skylight, glass façade, reflection of the indoor landscape.	Semi-open space, natural wind circulation.	4.30*	4.60*	Gives a spacious, fresh impression, supports a relaxed atmosphere; reduce the load on the air conditioner; Supports natural circulation & daytime lighting.
Munich	Skylight atrium, wide glass façade	Hybrid ventilation (mechanical	4.10*	4.50*	Provides visual comfort & stable temperature; supports daytime lighting;

Banyuwangi	with shading. Linear roof openings, diffuse skylights, hollow wooden façades.	& natural limited). Full tropical cross ventilation.	4.25*	4.70*	Suppress mechanical energy consumption. Creates a natural & comfortable feel; supports full cross ventilation; energy-saving cooling; suitable for tropical climates.

Table 5 shows the variation in natural lighting and ventilation strategies at the three airports. Scores marked with an asterisk (*) indicate qualitative evaluative ratings based on the researchers' analysis of natural lighting and ventilation strategies, including their psychological, thermal, energy, and environmental performance. Changi blends a modern feel with wide lighting, Munich emphasizes temperature stability with hybrid ventilation, while Banyuwangi highlights full tropical adaptation. The combined function shows that a biophilic approach to lighting and ventilation not only improves the quality of the space, but also supports energy efficiency and psychological comfort of the user.

3.6 Natural materials and cultural identity: Strengthening local contexts

The use of natural materials such as bamboo and wood at Banyuwangi Airport shows an approach rooted in the local architecture of Osing. Munich Airport utilizes natural stone and solid wood to reinforce the warm impression of Europe. Meanwhile, Changi Airport combines glass, metal, and vertical vegetation to display a tropical modern feel. The questionnaire score showed a positive acceptance of natural materials (4.33), but the cultural identity aspect obtained a lower score (3.89), indicating the need to strengthen local cultural representation. This study expands on the concept of biophilics (Han et al., 2020; Ryan et al., 2014) by emphasizing the role of material as a medium for strengthening cultural identity, not just an aesthetic element.

Table 6. Use of natural materials and cultural identity at airports case study

Airport	Main Natural Materials	Cultural Identity Approach	Material Score	Cultural Identity Score	Psychological, Cultural, & Environmental Functions
Changi	Glass, metal, vertical vegetation.	Modern tropical, global green symbol.	4.30*	3.90*	Creating a modern, fresh impression, supporting a green global image; enriches the experience of space but lacks a local context.
Munich	Natural stone, solid wood.	Warm European, regional contemporary feels.	4.20*	3.95*	It gives visual warmth, adds a connection to nature, reinforces the identity of modern Europe.
Banyuwangi	Bamboo, local wood, traditional weaving.	Osing vernacular, tropis kontekstual.	4.50*	3.80*	Reinforcing a sense of local cultural attachment, creating psychological comfort, supporting material sustainability.

Table 6 shows the variation of natural materials and approaches to cultural identity across all three airports. Scores marked with an asterisk (*) indicate values derived from qualitative assessment based on the study interpretative analysis of material use, cultural identity expression, and environmental-psychological functions across the selected airport case studies.Banyuwangi Airport displays the strongest efforts in using local materials and strengthening cultural expression. However, cultural identity scores are still relatively lower, signifying challenges in visually communicating cultural values to users. These results reinforce the novelty of research in linking biophilics with the strengthening of deep local contexts.

3.7 Psychological comfort and space circulation: Biophilic as a healing space

The psychological comfort of users at the airport is greatly influenced by the calm, open, and easy-to-understand atmosphere of the space (Wen et al., 2020). Changi and Banyuwangi airports stand out with spacious lounges, shaded vegetation, and intuitive and low-noise navigation paths. Munich Airport maintains clear circulation despite the more congested areas. The questionnaire scores showed a high appreciation of spatial navigation (4.56) and psychological comfort (4.11), confirming the importance of biophilic design in creating *a healing space* that supports the mental health of users. This research expands the concept of healing space, which has been widely applied to health facilities (Urban Land Institute (ULI), 2021), into an innovative strategy in large-scale public transportation spaces such as airports.

Table 7. Psychological comfort and space circulation at airport case study

Airport	Circulation & Navigation Approach	Psychological Comfort Strategies	Navigation Score	Psychological Comfort Score	Psychological & Spatial Function
Changi	Intuitive paths, open spaces, lots of indoor plants.	Quiet atmosphere, bright and spacious waiting room.	4.60*	4.20*	Creates a relaxation space experience, minimizes stress, supports natural orientation.
Munich	Clear lanes, large signage, enclosed public space integration.	Warm atmosphere, private rest area.	4.50*	4.00*	Provides a sense of security & comfort, supports visual connection.
Banyuwangi	Semi-outdoor natural trails, green transition areas.	Tropical open space, natural wind circulation.	4.70*	4.15*	Increases openness, calms, strengthens attachment to nature.

Table 7 shows how each airport adapted the concepts of psychological comfort and spatial navigation as part of a biophilic design. Banyuwangi Airport excels at creating a sense of tropical openness, while Changi emphasizes tranquility and ease of orientation. Munich, although more dense, still maintains the clarity of the route. The high questionnaire scores on navigation and psychological comfort strengthen the argument that biophilic design is able to support *healing spaces* as well as the efficiency of user flow in public transit spaces.

3.8 Sustainability support and public enthusiasm

Users show a very high appreciation and support for the implementation of sustainability principles at airports. This is reflected in the public support score of 4.89 and the sustainability perception score of 4.33. This data shows that the concept of biophilics is not only appreciated as an aesthetic aspect, but also as a representation of commitment to environmental sustainability. This research expands the sustainability discourse that has been focusing on technical aspects by emphasizing the importance of public acceptance and enthusiasm as an indicator of social success in sustainable architecture.

Table 8. Perceptions of sustainability and public support at airports case study

Airport	Sustainability Approach	Public Support Approach	Sustainability Score	Public Support Score	Psychological, Social, & Environmental Function
Changi	Integration of indoor garden, green building, natural lighting.	Ecological education through the Rain Vortex landmark.	4.40*	4.90*	Building pride, raising ecological awareness, strengthening the global green image.
Munich	Green roof, rainwater management, mechanical energy efficiency.	Sustainability communication through public spaces & signage.	4.30*	4.85*	Strengthen environmental awareness, create a sense of comfort, support environmentally friendly behavior.
Banyuwangi	Full natural ventilation, local materials, open tropical landscape.	Emphasis on local wisdom & the invitation to "eco-local".	4.30*	4.95*	Strengthen cultural attachments, encourage a sense of belonging, and support sustainable tropical adaptation.

Table 8 shows the differences in the sustainability approaches applied to the three airports. Changi combines indoor gardens as global ecological icons, Munich emphasizes energy efficiency technology, while Banyuwangi prioritizes local tropical adaptation. The high public support score shows that sustainability is not only of technical value, but also of building an emotional connection between users and spaces. These findings reinforce the novelty of the research, which emphasizes biophilics as a bridge between sustainability strategies and social acceptance.

3.9 Triangulation of findings: Qualitative and quantitative integration

As the final stage of discussion, this study triangulates between qualitative findings (observation results, document analysis, and narrative answers) and quantitative findings (questionnaire scores). This triangulation aims to strengthen the validity of the data while affirming the biophilic contribution to cross-climatic and cultural airport architecture. A summary of the integration of qualitative and quantitative results is shown in Table 9.

Based on the integration of qualitative and quantitative findings, this study confirms that the application of biophilic design in airport architecture not only strengthens aspects of environmental sustainability, but also creates public spaces that support psychological comfort, cultural identity, and collective pride of users. The different approaches in Changi, Munich, and Banyuwangi show that biophilic design is able to be contextually adapted according to the local climate and culture, while offering an innovative contribution in expanding the green architecture paradigm in the realm of global transportation.

Table 9. Triangulation of qualitative and quantitative analysis results

Theme	Qualitative Findings	Average Quantitative Score	Interpretation & Implications
The Elements of Nature	The presence of an indoor garden, green roof, local vegetation, pond & waterfall.	Vegetasi: 4.78; Air: 4.56	Natural elements reinforce the landmarks of the space, support natural cooling, as well as enhance psychological comfort.
Lighting & Ventilation	Skylight, glass façade, tropical cross ventilation, semi-outdoor space.	Illumination: 4.22; Ventilation: 4.56	Adaptive strategies support energy efficiency, thermal comfort, and psychological qualities of users.
Material & Cultural Identity	Local materials (bamboo, wood), natural stone, wicker, vertical vegetation.	Material: 4.33; Identity: 3.89	Natural materials reinforce emotional closeness, but cultural identity still requires visual reinforcement.
Psychological Comfort & Circulation	Intuitive paths, open spaces, spacious lounges, interior vegetation.	Navigation: 4.56; Psychological: 4.11	Biophilic supports healing space and smooth user flow, improving the quality of transit.
Sustainability & Public Support	Green building, natural ventilation, public education, open green spaces.	Sustainability: 4.33; Support: 4.89	Public support is very high, reinforcing biophilics as a social and environmental sustainability strategy.

4. Conclusion

This research shows that the application of biophilic design in airport architecture not only plays a role as an aesthetic element, but also as an integral strategy in supporting environmental sustainability, psychological comfort, and strengthening cultural identity. A comparative study of Changi, Munich, and Banyuwangi Airports shows a variety of contextual approaches, adjusting to the climate, culture, and local preferences of each region. The integration of natural elements, such as indoor gardens, local vegetation, green roofs, and indoor waterfalls, is proven to create a fresh, soothing atmosphere, as well as reinforce psychological landmarks that enhance the airport's image. Quantitative data support this, with an average high perception score on the vegetation variable (4.78) and water element (4.56). Natural lighting strategies (skylights, glass façades) and tropical cross ventilation also support energy efficiency and thermal comfort, as reflected in the average scores of ventilation (4.56) and lighting (4.22).

The use of natural materials such as wood, bamboo, and natural stone reinforces the emotional closeness of the user, although aspects of cultural identity still require more in-depth visual and narrative reinforcement. This is reflected in the relatively lower cultural identity score (3.89), indicating the potential to enrich local representation. Banyuwangi Airport, for example, has managed to utilize local materials and show strong tropical adaptation, while Munich Airport emphasizes European warmth through natural stone and solid wood. From the aspect of psychological comfort, the spacious waiting room, intuitive navigation, and the existence of a semi-outdoor area are important factors in supporting healing spaces and reducing passenger stress. High average scores on the variables of spatial navigation (4.56) and psychological comfort (4.11) reinforce the finding that biophilic design contributes significantly to the quality of the experience at airports.

Furthermore, the high public support for sustainability principles (average score of 4.89) confirms that biophilics is not only accepted as a design innovation, but also as a form of social and ecological commitment that increases the pride and emotional attachment of users. The integration of qualitative data (NVivo thematic analysis) with quantitative data (SPSS) in this study shows the consistency of cross-airport findings and strengthens the validity of the results.

Thus, this study confirms that the application of biophilic design at airports is able to optimize environmental performance, support energy efficiency, and enrich the quality of public spaces and cultural identity. The different approaches in the three case study airports prove that biophilics is a flexible and adaptive strategy that can be applied contextually according to local needs. These findings are expected to be a practical and theoretical reference for architects, airport managers, and policymakers in designing transportation infrastructure that is greener, more sustainable, and focused on user welfare. This study proposes several strategic recommendations for advancing biophilic-based airport architecture. Key priorities include strengthening local cultural identity through the integration of natural materials and cultural elements, and enhancing natural lighting and ventilation using adaptive and AI-based technologies to improve energy efficiency and user comfort. Increasing public education and engagement on sustainability is also essential to foster awareness and a sense of belonging. Future research should expand across diverse geographic and cultural contexts to enrich understanding of adaptive biophilic strategies. Additionally, multidisciplinary collaboration is crucial to support holistic and innovative design solutions. Finally, the development of national technical guidelines, particularly in Indonesia, is recommended to standardize biophilic and sustainable practices in airport and public transport infrastructure, while supporting net-zero emission goals.

Acknowledgement

The author would like to express his deepest gratitude to Mrs. Prof. Dr. Ars. Eko Nursanty, ST, MT, S.T., M.T. for his invaluable guidance, support, and direction during the process of compiling this journal. He has provided in-depth scientific insights and extraordinary motivation, which has been instrumental in enriching the quality of this research. Without Mother's help, attention, and dedication, this work would not have been able to materialize properly. Thank you for your time and commitment.

Author Contribution

The author was solely responsible for the conceptualization, data collection, analysis, and writing of the manuscript.

Funding

This research received no external funding.

Ethical Review Board Statement

Not available.

Informed Consent Statement

Not available.

Data Availability Statement

Not available.

Conflicts of Interest

The author declare no conflict of interest.

Declaration of Generative AI Use

During the preparation of this work, the author used AI to assist in improving grammar, clarity, and academic tone of the manuscript. After using this tool, the author reviewed and edited the content as needed and took full responsibility for the content of the publication.

Open Access

References

Airports Council International. (2022). Airport industry outlook. *Airports Council International*. https://www.aci-asiapac.aero/media-centre/library?c=economics&y=&p=2

Anastya, K., & Aletta, F. (2025). Biophilia in Transit: Exploring the Impact of Indoor Plants on Wellbeing in Airports. *Buildings*, *15*(22), 4065. https://doi.org/10.3390/buildings15224065

Andra Matin Architect. (2018). Banyuwangi International Airport: A green airport in Indonesia. *Andra Matin Architect*. http://andramatin.com

Ariff, A. A. A., Shahril, M. I. S. M., Samadi, Z., & Mohamad, E. (2025). The Importance of Green De-Stress Relief Spaces in Malaysian Airports: Enhancing Traveller Well-Being and Environmental Sustainability. In *Sustainable Green Infrastructure: Materials and Technologies* (pp. 155-174). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-96-1486-8_9

Bamidele, R. O., Ozturen, A., Haktanir, M., & Ogunmokun, O. A. (2023). Realizing green airport performance through green management intransigence, airport reputation, biospheric value, and eco-design. *Sustainability*, *15*(3), 2475. https://doi.org/10.3390/su15032475

Browning, W. D., Ryan, C. O., & Clancy, J. O. (2014). *14 Patterns of Biophilic Design*. Terrapin Bright Green. https://www.terrapinbrightgreen.com/wp-content/uploads/2014/09/14-Patterns-of-Biophilic-Design-Terrapin-2014p.pdf

Changi Airport Group. (2020). Changi takes big steps to go green. Changi Airport Group. https://www.changiairport.com/corporate/media-centre/changijourneys/the-airport-never-sleeps/changi-takes-big-steps-to-go-green.html

Creswell, J. W., & Clark, V. L. P. (2018). *Designing and Conducting Mixed Methods Research* (3 ed.). SAGE Publications, Inc.

El Zein, M., Karimipanah, T., & Ameen, A. (2025). Airports—Energy and sustainability perspectives. *Energies*, *18*(6), 1360. https://doi.org/10.3390/en18061360

Florido-Benítez, L. (2022). How Málaga's airport contributes to promote the establishment of companies in its hinterland and improves the local economy. *International Journal of Tourism Cities*, *8*(2), 393-411. https://doi.org/10.1108/IJTC-04-2021-0059

Franciscone, B. G., Zou, X., & Fernandes, E. (2024). The Global South Air transport Belt: A catalyst for sustainable tourism and economic growth. *Transport Policy*, *159*, 14-27. https://doi.org/10.1016/j.tranpol.2024.09.018

Ghrab, A., & Feiz, A. A. (2025). Innovative Architecture: Sustainable Design and the Role of Bio-Based Materials. In *International Conference on Bio-Based Building Materials* (pp. 703-716). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-92777-5_56

Gössling, S., & Upham, P. (2009). *Climate Change and Aviation: Issues, Challenges and Solutions*. Earthscan.

Han, H. (2020). Eco-design of airport buildings and customer responses and behaviors: Uncovering the role of biospheric value, reputation, and subjective well-being. *Sustainability*, *12(23)*(10059). https://doi.org/10.3390/su122310059

IATA. (2023). *Global Outlook for Air Transport: A local sweet spot.* International Air Transport Association. https://www.iata.org/en/iata-repository/publications/economic-reports/global-outlook-for-air-transport---december-2023---report/

Kanyio, O. A., Gbadamosi, K. T., & Omole, F. K. (2023). Airport changing business model and density of economic activities. *International Journal of Research and Innovation in Social Science (IJRISS), V11*, *11*, 363-375. https://doi.org/10.47772/IJRISS

Kellert, S. R. (2008). *Biophilic design: The theory, science, and practice of bringing buildings to life.* Wiley.

Kellert, S. R. (2018). *Nature by design: The practice of biophilic design*. Yale University Press.

Kementerian Perhubungan Republik Indonesia. (2020). Bandara Banyuwangi: Penerapan desain tropis pasif. *Kementerian Perhubungan RI*. http://dephub.go.id

Khanna, A., & Swami, S. (2025). Sustainable management of airports: a managerial review. *Journal of Advances in Management Research* *23*(1): 148–162. https://doi.org/10.1108/JAMR-03-2024-0122

Newman, P., & Kenworthy, J. (2015). *The End of Automobile Dependence: How Cities are Moving Beyond Car-Based Planning*. Island Press.

Ryan, C. O., Browning, W. D., Clancy, J. O., Andrews, S. L., & Kallianpurkar, N. B. (2014). Biophilic Design Patterns: Emerging Nature-Based Parameters for Health and Well-Being in the Built Environment. *International Journal of Architectural Research: ArchNet-IJAR*, *8*(2), 62. https://doi.org/10.26687/archnet-ijar.v8i2.436

Santa, S. L. B., Ribeiro, J. M. P., Mazon, G., Schneider, J., Barcelos, R. L., & de Andrade, J. B. S. O. (2020). A Green Airport model: Proposition based on social and environmental management systems. *Sustainable Cities and Society*, *59*, 102160. https://doi.org/10.1016/j.scs.2020.102160

Schlenker, W., & Walker, W. R. (2016). Airports, Air Pollution, and Contemporaneous Health. *The Review of Economic Studies*, *83*(2), 768–809. https://doi.org/10.1093/restud/rdv043

Sreenath, S., Sudhakar, K., & Yusop, A. F. (2021). Sustainability at airports: Technologies and best practices from ASEAN countries. *Journal of environmental management*, *299*, 113639. https://doi.org/10.1016/j.jenvman.2021.113639

Tabassum, R. R., & Park, J. (2024). Development of a building evaluation framework for biophilic design in architecture. *Buildings*, *14*(10), 3254. https://doi.org/10.3390/buildings14103254

Urban Land Institute (ULI). (2021). *An airport in harmony with nature*. https://urbanland.uli.org

Wen, L., Kenworthy, J., & Marinova, D. (2020). Higher density environments and the critical role of city streets as public open spaces. *Sustainability*, *12*(21), 8896. https://doi.org/10.3390/su12218896

Wilson, E. O. (1984). *Biophilia*. Harvard University Press.

Wired. (2008). “Dragon” Airport Reveals Its Vast Span for Beijing Olympics. https://www.wired.com/2008/02/dragon-airport

Yildiz, O. F., Yilmaz, M. E. H. M. E. T., & Celik, A. (2022). Reduction of energy consumption and CO2 emissions of HVAC system in airport terminal buildings. *Building and Environment*, *208*, 108632. https://doi.org/10.1016/j.buildenv.2021.108632

Zhang, F., & Graham, D. J. (2020). Air transport and economic growth: a review of the impact mechanism and causal relationships. *Transport Reviews*, *40*(4), 506-528. https://doi.org/10.1080/01441647.2020.1738587

Biography of Author

Isdanto Rahusodo, Department of Architecture, Universitas 17 Agustus 1945 Semarang, Semarang, Central Java 50263, Indonesia.

- Email: isdanto.rahusodo@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A