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Integration of Biophilic Design Principles with Sustainable Development Goals (SDGs)

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Abstract:

This research paper explores the potential of integrating biophilic design principles within the framework of the Sustainable Development Goals (SDGs) to promote environmental sustainability, human well-being, and social equity. By examining the intersections between biophilic design and the SDGs, this study aims to elucidate the ways in which biophilic design can contribute to the advancement of sustainable development objectives. Through a comprehensive review of literature and theoretical analysis, the research investigates the role of biophilic design in addressing key challenges outlined in the SDGs, such as climate action, sustainable cities and communities, and health and well-being. The findings of this study offer insights into the potential of biophilic design to serve as a catalyst for achieving the SDGs, providing valuable implications for policymakers, designers, and practitioners seeking to create more sustainable and human-centered built environments.

In addition, Biophilic design, rooted in the innate human connection to nature, offers a framework for creating built environments that foster human well-being while minimizing environmental impact. This paper reviews the theoretical foundations of biophilic design and its relevance to sustainable architecture, emphasizing the potential synergies between nature-inspired principles and sustainable design practices. The findings highlight the potential of biophilic design to enhance occupant well-being, improve building performance, and contribute to the overall sustainability of the built environment. By elucidating the practical implications and theoretical underpinnings of biophilic design in sustainable architecture.

Keywords:

Biophilic design, Biophilic architecture, Sustainable architecture, Biophilic principles and Sustainable Development Goals (SDGs).

Research problem:

Although the goals of sustainable architecture are to reduce the negative effects on the environment and to improve human well-being, further research is required to determine whether biophilic design concepts may be incorporated into built environments to improve their sustainability and livability. Understanding how biophilic design can be applied to sustainable architecture is the research problem. This includes addressing issues regarding how well nature-inspired design principles can improve environmental performance, occupant well-

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
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being, and the overall sustainability of architectural design. Additionally, there is a need to investigate the practical challenges and opportunities associated with implementing biophilic design within the context of Sustainable Development Goals. By addressing these research questions, this study seeks to advance our understanding of the role of biophilic design in sustainable architecture and provide valuable insights for architectural practice and theory.

Research Aims and Objectives

Aims:

- To investigate the potential of integrating biophilic design principles within the Sustainable Development Goals (SDGs) framework to promote environmental sustainability, human well-being, and social equity.
- To assess the effectiveness of integrating biophilic design principles within the Sustainable Development Goals (SDGs).

Objectives:

- To review existing literature on biophilic design and the Sustainable Development Goals (SDGs) to identify key intersections and potential areas of impact.
- To assess the specific ways in which biophilic design interventions can contribute to addressing key sustainability challenges outlined in the Sustainable Development Goals (SDGs), such as climate action, sustainable cities and communities, and health and well-being.
- To identify potential barriers and opportunities associated with the implementation of biophilic design principles in the context of the Sustainable Development Goals (SDGs), considering factors such as policy, design practices, and stakeholder engagement.
- To provide actionable recommendations for policymakers, designers, and practitioners on leveraging biophilic design as a strategic tool for advancing sustainable development objectives outlined in the Sustainable Development Goals (SDGs).

Research Methodology:

The research methodology relied on two approaches as follows:

- **Literature Review:** Conduct a comprehensive review of existing literature on biophilic design and the Sustainable Development Goals (SDGs). This will provide a foundational understanding of the concepts, theories, and previous research in the field.
- **Comparative Analysis:** Conduct a comparative analysis of biophilic design principles and the Sustainable Development Goals (SDGs). This comparative approach will help assess the tangible benefits of biophilic design within the context of the SDGs.

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

1- Introduction

In recent years, the field of architecture has witnessed a paradigm shift towards sustainable and environmentally conscious design practices. This shift has been fueled by the growing awareness of the detrimental impact of traditional architectural approaches on the natural environment and human well-being. As a response to this, architects and designers have increasingly turned to biophilic design principles as a means to create built environments that not only minimize their ecological footprint but also foster a deeper connection between occupants and the natural world.

Biophilic design, rooted in the concept of biophilia - the innate human affinity for nature, offers a framework for integrating natural elements, processes, and patterns into the built environment. By drawing inspiration from nature, biophilic design seeks to create spaces that support human health and well-being, enhance productivity, and reduce stress. Moreover, it aims to contribute to the conservation and restoration of ecosystems, thereby promoting a more sustainable relationship between the built environment and the natural world (Prakash Nair, 2022).

A Historical Overview of 'Nature' in Architecture

The concept of biophilic design finds its roots in humanity's age-old affinity for nature. Throughout history, various civilizations have incorporated natural elements into their built environments, recognizing the restorative and inspirational qualities of the natural world. From the gardens of ancient Babylon. to the courtyards of Islamic architecture (Fig. 1), historical examples abound of human attempts to integrate nature into the man-made environment (Wynants, 2021).

Fig. 1 (a) The Hanging Gardens of Babylon. (b) The Islamic Courtyard.
Source: (Heemskerck, 2018).

In the modern era, the Industrial Revolution brought about a significant shift in architectural practices, leading to the rise of urbanization and industrialization. This period witnessed a departure from nature-inspired design as buildings became increasingly utilitarian and disconnected from the natural world. However, the detrimental environmental and social impacts of this approach became increasingly apparent over time, leading to a renewed interest in sustainable and human-centric design principles (Phillip James Tabb, 2014).

The term "biophilia" was popularized by biologist E.O. Wilson in the 1980s, referring to the innate human inclination to connect with nature. This concept laid the foundation for the emergence of biophilic design as a framework for creating built environments that foster a deeper connection with nature. Architects and designers began to explore ways to reintegrate natural elements, patterns, and processes into their designs, aiming to enhance human well-being, productivity, and environmental sustainability (Berto, 2021).

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

2- Biophilia and Biophilic Design

2.1- Definition of Biophilia

The origins of the word "biophilia" go back to the ancient Greek language. The word "bio" means life and "philia" means love. The whole world is an expression of love for life.

Biophilia literally means love of nature, and this is due to the fact that humans have the instinct to connect and be close to nature. It is that human tends to belong to the natural systems and processes and the life and vital features of the non-human environment surrounding human (Cleveland, 2014).

Fig. 2 - Connection Between Nature and Humans (K, n.d.).

2.2- Biophilic Design

In 1965, the term "biophilic design" was appeared. The term "biophilia" was coined by German/American social psychologist Erich Fromm, who described it as "the love of life" or "living things." Edward Wilson, an American scientist, postulated that humans are genetically predisposed to a state of balance with the natural world. It aims to use natural resources as efficiently as possible. "Biophilic design" refers to the concept of integrating nature into built environments, which was first proposed by social ecology professor Stephen R. Kellert. The concept of biophilia is not limited to interior design or architecture; it is also present in more fields of study that are all influenced by nature. (Prakash Nair, 2022).

Biophilic design is focused on creating strong connections between nature and manmade environments which can have benefits for health and wellbeing. The term "biophilic architecture" refers to adaption or design of a building to the environment (K.Hejiib, 2021).

2.3- Biophilic Design Principles and Framework

For most of history, humans have spent their time outside- the relatively recent change to indoor living is something that our bodies might not have fully adapted to yet. Biophilic design allows us to interact with nature without compromising our modern lifestyle, these principles are a set of guidelines and concepts that aim to incorporate nature and natural elements into the built environment to create spaces that support human well-being. These principles are based on the idea that humans have an innate connection to nature and that integrating natural elements into our surroundings can have a positive impact on our health and productivity. So, several design frameworks were proposed. Dimensions, Elements and Attributes of Biophilic Design, The Practice of Biophilic Design, and 14 Patterns of Biophilic Design are the most commonly used and endorsed more detailed perspectives (Tekin, 2023) (Indre Grazuleviciute-Vileniske, 2022).

- **The First Classification:** Created by Kellert in 2004 for the biophilic design features was produced (Kellert, 2004). His classification included 17 common features, as follows (Table 1):

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

Table 1 - Common Features of Biophilic Design (Kellert, 2004) (Author).

Common Features of Biophilic Design	1. Natural lighting 2. Natural Ventilation 3. Natural Materials 4. Natural and Indigenous Vegetation 5. Ecological Landscape Design 6. Open Space 7. Water views and Vistas of Nature 8. Shapes and forms that mimic organic forms 9. Vistas characterized by refuge and prospect 10. Natural features that evoke mystery 11. Exploration and Enticement 12. Natural features characterized by order and complexity 13. Natural Rhythms 14. Natural processes and change 15. Aesthetic and recreational values of nature 16. Informational and intellectual values of nature 17. Emotional and Spiritual values of nature

- **The Second Classification:** Created by Kellert in 2008 for the biophilic design elements was produced (Stephen R. Kellert, 2008). His classification included six main biophilic design elements that represented 72 biophilic design elements and attributes (Fig. 3):

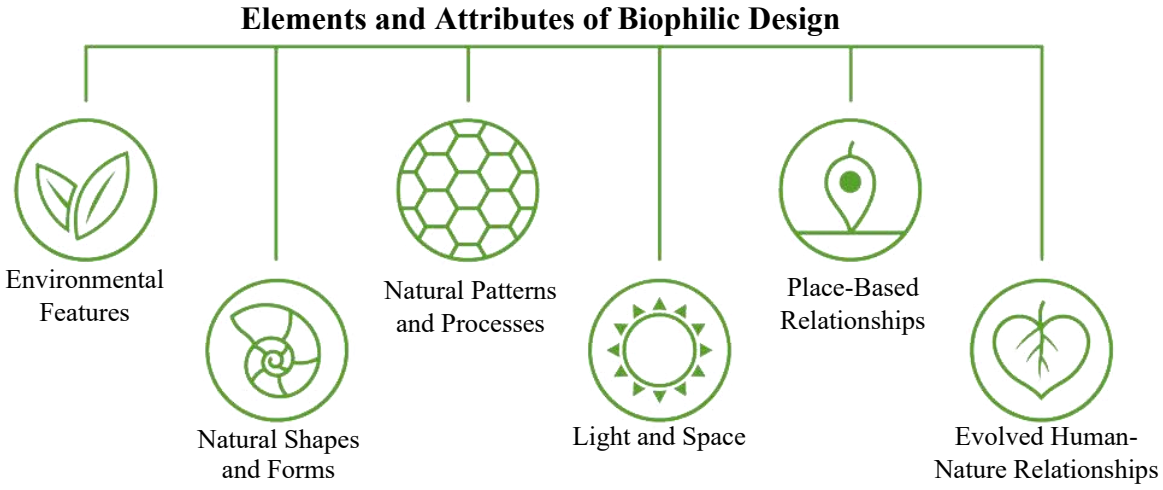


Fig. 3 - Elements and Attributes of Biophilic Design (Limited, 2022) (Author).

The author emphasised that this framework did not specify any building typology or did not demonstrate any comparison between different parameters. because this work was still in progress, and the framework will be modified in the future as knowledge in this area increases, leading to some of the categories might overlap.

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

➢ **The Third Classification:** Therefore, Kellert presented a more organised and more focused new framework in 2015 and it's updated in 2018, The Practice of Biophilic Design (Stephen R. Kellert, Calabrese and Elizabeth F., 2015) (Wynants, 2021). There classification included 24 attributes under three main categories (Fig. 4):

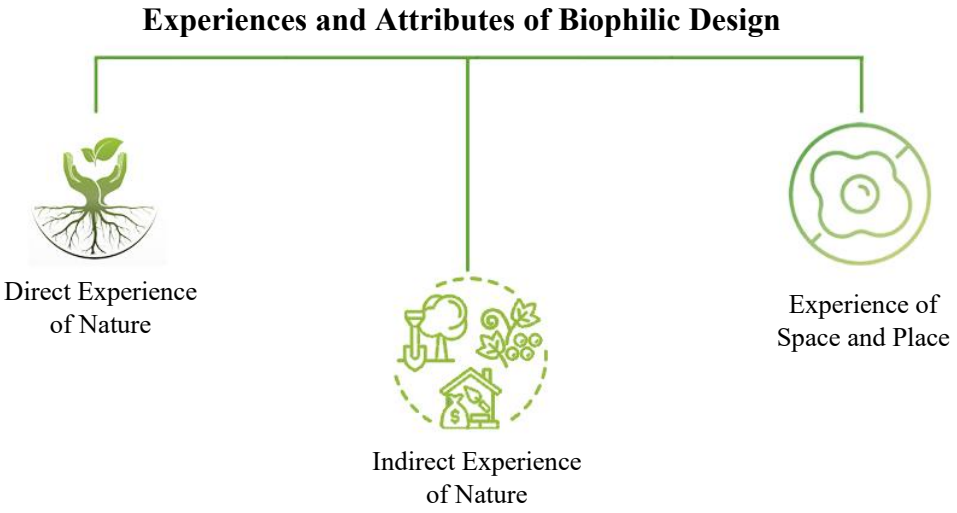


Fig. 4 - Experiences and Attributes of Biophilic Design (Author).

➢ **The Forth Classification:** In 2014, The 14 Patterns of Biophilic Design booklet, published, introduced a new framework by considering biophilic design parameters in an interdisciplinary context. (William Browning, 2014). The framework developed in 2020 by Terrapin Bright Green LLC framed biophilic design parameters within 14 titles by naming them "patterns", and classified them within three main categories, as follows (Fig. 5) (Table 2):

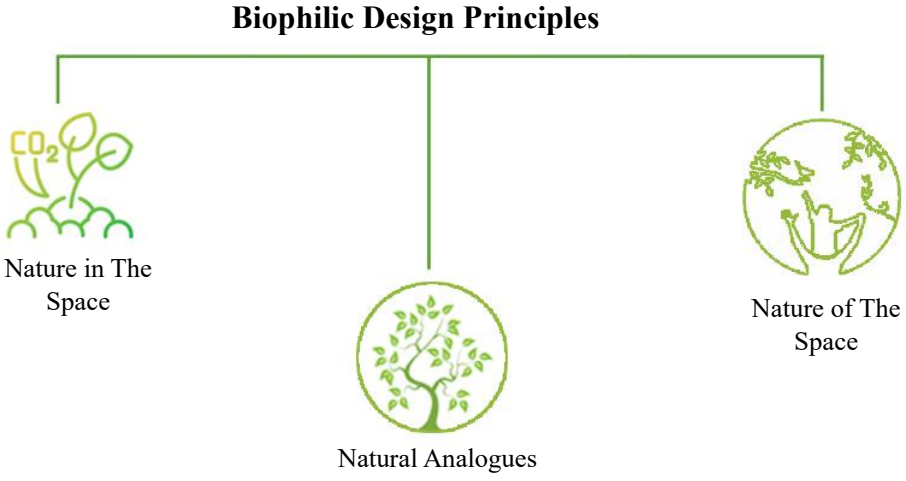


Fig. 5 - Biophilic Design Principles (Author).

Following the presentation of various classifications, we selected the most recent one as a framework to biophilic design. The table (Table 2) below display the biophilic design principles description.

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

Table 2 - Biophilic Design Principles (William Browning, 2014) (Wynants, 2021) (Prakash Nair, 2022) (Stephen R. Kellert, Calabrese and Elizabeth F., 2015) (Author).

Biophilic Design Principles		Description
Nature in The Space	Visual Connection with Nature	It emphasizes the importance of incorporating elements of nature into the built environment to create a visual link between indoor spaces and the natural world. This can be achieved through the use of windows that offer views of natural landscapes, indoor gardens, or the strategic placement of natural materials and colors within architectural design.
	Non-Visual Connection with Nature	It refers to the incorporation of natural elements and experiences that engage senses other than sight, such as touch, smell, and sound, to create a connection to the natural world within the built environment.
	Non-Rhythmic Sensory Stimuli	It is used to describe sudden, brief events that can be either artificial or natural. This can include things like the random rustling of leaves, the irregular movement of water, or the unpredictable sounds of wildlife.
	Thermal & Airflow Variability	It refers to need a fresh air, a fitting temperature, the right humidity and surface temperatures that imitate nature.
	Presence of Water	It aims to connect occupants with nature by incorporating water features into the built environment. This can include indoor water fountains, reflecting pools, or even natural water bodies like ponds or streams in outdoor spaces.
	Dynamic & Diffuse Light	It refers to the intentional use of varying natural light patterns and qualities within a space. Dynamic light encompasses the changes in light intensity and direction that occur throughout the day, while diffuse light refers to the soft, even illumination that results from light scattering.
	Connection with Natural Systems	It emphasizes the integration of built environments with natural ecosystems and processes. This can involve incorporating elements such as green roofs, rain gardens, or natural water filtration systems to mimic and interact with the surrounding natural environment.
Natural Analogues	Biomorphic Forms & Patterns	Include organic shapes that use curvy lines, patterns, textures, and numerical arrangements that exist in nature.
	Material Connection with Nature	Nature-inspired materials and characteristics that incorporating natural materials, such as wood, stone, or water, into the built environment to create a tangible and sensory connection to the natural world.
	Complexity & Order	Substantial sensorial information is organized a large building comparable to that seen in nature.
Nature of The Space	Prospect	It refers to the ability to see and observe the surrounding environment from a vantage point within a space.
	Refuge	It pertains to the creation of spaces within the built environment that offer a sense of safety, security, and retreat.
	Mystery	People want to explore and understand. A place with partially obscured views gives a sense of mystery and compels to investigate.
	Risk/Peril	A known threat paired with consistent safety.

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

3- Sustainable Development Goals (SDGs)

In 2015, all the countries in the United Nations adopted the 2030 Agenda for Sustainable Development. It sets out 17 Goals, which include 169 targets. These wide-ranging and ambitious Goals interconnect. Goal 3 is to ensure healthy lives and promote well-being for all at all ages. But it is also cross-cutting, so that progress in its implementation contributes to progress towards other Goals, and action on other Goals in turn contributes to attaining Goal 3. Most of the Goals also have some direct health targets. All of them have indicators by which progress can be measured (Communications, 2023).

The Sustainable Development Goals (SDGs) aim to transform our world. They are a call to action to end poverty and inequality, protect the planet, and ensure that all people enjoy health, justice and prosperity. It is critical that no one is left behind.

Fig. 6 – Sustainable Development Goals (SDGs) (Camp, 2020).

➢ What's different about the Sustainable Development Goals?

The 2030 Agenda and its Goals offer a comprehensive vision for sustainable development that:

- Is global, rather than limited to "developing" countries as was the case with the Millennium Development Goals (MDGs).
- Is based on values such as equity and respect for human rights.
- Relies on approaches such as sustainable financing, scientific research and innovation, and monitoring and evaluation.
- Requires a new way of working, involving intersectoral action by multiple stakeholders;
- Aims to strengthen health systems towards universal health coverage (UHC) (Organization, n.d.).

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

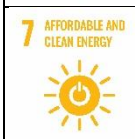
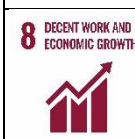
Sustainable Development Goals (SDGs)	Description		
	Affordability of housing.		Reduce inequality within and among countries.
	End hunger, achieve food security and improved nutrition and promote sustainable agriculture.		Make cities and human settlements inclusive, safe, resilient and sustainable.
	Ensure healthy lives and promote well-being for all at all ages.		Ensure sustainable consumption and production patterns.
	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.		Take urgent action to combat climate change and its impacts.
	Achieve gender equality and empower all women and girls.		Conserve and sustainably use the oceans, seas and marine resources for sustainable development.
	Ensure availability and sustainable management of water and sanitation for all.		Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation.
	Ensure access to affordable, reliable, sustainable and modern energy for all.		Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective at all levels.
	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.		Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development.
	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.		

Table 3 - Sustainable Development Goals (SDGs) (Communications, 2023) *(Camp, 2020)*(Author).

4- Integration of Biophilic Design Principles with Sustainable Development Goals (SDGs)

In response to the growing need for sustainable, resilient, and human-centered urban development, we present the Biophilic Design Framework for Sustainable Development. This innovative framework aims to integrate biophilic design principles with the Sustainable Development Goals (SDGs) to identify strengths and weaknesses between biophilic design principles and Sustainable Development Goals (SDGs). As follows (Table 4):

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

Sustainable Development Goals (SDGs)	Biophilic Design Principles													
	Nature in the space							Natural Analogues			Nature of The Space			
	Visual Connection with Nature	Non-Visual Connection with	Non-Rhythmic Sensory Stimuli	Thermal & Airflow Variability	Presence of Water	Dynamic & Diffuse Light	Connection with Natural Systems	Biomorphic Forms & Patterns	Material Connection with	Complexity & Order	Prospect	Refuge	Mystery	Risk/Peril
 No Poverty									■			■		■
 Zero Hunger	■									■				
 Good Health & Well-Being	■	■	■	■	■	■	■	■	■		■	■		■
 Quality Education	■			■										■
 Gender Equality														
 Clean Water & Sanitation					■									■
 Affordable & Clean Energy	■			■	■	■	■	■	■					■
 Decent Work & Economic Growth	■	■	■	■		■	■		■					■
 Industries, Innovation & Infrastructure	■	■	■	■	■	■	■	■	■	■				■

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

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Reduced Inequalities														
Sustainable Cities & Communitas														
Responsible Consumption & Production														
Climate Action														
Life Below Water														
Life on Land														
Peace, Justice & Strong Institutions														
Partnerships for the Global														
Score (out of 17)	10	6	5	9	8	8	9	7	11	6	2	3	1	8
%	58.8%	35.3 %	29.4%	52.95%	47%	47%	52.95%	41.2%	64.7 %	35.3 %	11.75%	17.65%	5.9%	47%

Table 4 - Integration of Biophilic Design Principles with SDGs (Author).

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

5- Discussion

The Sustainable Development Goals (SDGs) and biophilic design concepts are interconnected in various respects, since they both seek to improve human well-being and promote a healthier, more sustainable planet. Biophilic design can play a significant role in achieving sustainable development goals. The following part illustrated the relation and interconnection between each of the sustainable development goals with biophilic design principles resulted from the table above.

The relationship between the Sustainable Development Goals (SDGs) and biophilic design concepts illustrated in the table above are coloured with different colour codes based on how high or low the interconnection exists between both. The Green shade illustrates high interconnection the Sustainable Development Goals (SDGs) and Biophilic design principles; medium interconnectedness is represented by the yellow shade. Lastly, the orange shade illustrates how little the Sustainable Development Goals (SDGs) and the concepts of biophilic design are interconnected.

➢ SDG 1 -No Poverty

Interconnection between SDG 1 "No Poverty" and Biophilic Design principles is low, where it is only connected with 3 principles:

- **Material Connection with Nature:** Natural components are frequently incorporated into construction and design, with materials derived from local ecosystems to create more affordable and sustainable housing solutions for individuals and families facing poverty. In addition to that, it can stimulate local economies, providing income-generating opportunities for communities and contributing to poverty reduction.

- **Refuge:** Biophilic design concepts can be used to build affordable and accessible refuge areas. By incorporating natural elements into the design of shelters and houses for the poor, it is feasible to improve living conditions without considerably increasing expenditures.

- **Risk:** Addressing risk in biophilic design may contribute to alleviate poverty by developing stronger and more resilient ecosystems. Designing with an awareness of natural risks and disasters can lead to the incorporation of features that mitigate potential harm.

  For example, Biophilic principles of design can be used to improve building and community resilience to climate-related risks such as floods, storms, and severe temperatures. Furthermore, green infrastructure, such as vegetative barriers, can help reduce the impact of floods or landslides, contributing to the safety and well-being of vulnerable people.

This approach not only enhances the safety and well-being of communities facing poverty but also contributes to long-term economic stability and development.

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

➢ **SDG 2 - Zero Hunger**

There is no direct interconnection between Biophilic Design Principles and SDG 2. But it can support this goal by promoting sustainable food systems and agriculture through the use of green roofs, green walls, urban farms, and other forms of urban agriculture.

➢ **SDG 3 - Good Health and Well-being:**

The use of biophilic design helps to create environments that enhance both physical and emotional well-being. Access to greenery, sunlight, and wildlife can improve mood, lessen stress levels, and promote overall well-being. Given that multiple biophilic design principles are related to numerous sustainable development goals, the following table shows that the relationship between this SDG and biophilic design principles is one of the strongest. The following are the interrelated SDGs:

- **Visual connection with nature:** Exposure to nature, even in little amounts, can have a significant positive impact on human health. Exposure to outdoors and landscapes of greenery can promote mental health by providing a sense of calm and relaxation.
- **Non-visual connections with nature** and **Non-rhythmic sensory stimuli** are similar to each other. They both play a vital role in biophilic design, which aims to engage the senses beyond sight and contribute to a multi-sensory experience that connects people to a more holistic and immersive environment. By embracing non-visual connections with nature, Biophilic design attempts to create places that stimulate a wide range of sensory experiences, creating a deeper connection with the natural world. This holistic approach helps to improve well-being, reduce stress, and provide an overall better experience in the built environment.
- **Thermal and Airflow variability:** Biophilic design principles can be applied to address thermal variability in the built environment. Thermal variability refers to fluctuations in temperature, and biophilic design seeks to create spaces that respond to and integrate with natural environmental conditions. Biophilic design promotes the use of natural ventilation mechanisms, which assist regulate indoor temperatures and reduce the need for mechanical cooling in response to thermal variability. This leads to the comfort of individuals and thus their well-being in space.
- **Presence of water:** Water features are essential components of biophilic design, offering both visual and non-visual ties to nature. Access to water features, both indoors and outdoors, can improve mental health. It helps to reduce stress, boost mood, and develop a closer connection to nature, all of which add to inhabitants' overall well-being.
- **Dynamic & Diffuse Light:** Light is an essential factor that affects circadian cycles, mood, and general physiological health. In biophilic design, dynamic and diffuse lighting can mirror natural variations in light intensity and colour temperature throughout the day. This helps regulate circadian rhythms, which are essential for maintaining a balanced sleep-wake cycle and overall well-being.
- **Connection to Natural Systems:** Biophilic design creates a sense of connection to nature, whether through the use of natural materials, nature-inspired patterns, or direct views of outdoor environments. This relationship has been related to better mental health and a sense of purpose.

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

- **Biomorphic Forms & Patterns:** Biomorphic forms and patterns offer visual interest and complexity to spaces, capturing attention and promoting engagement. This visual stimulation adds to a more dynamic and attractive environment. Biomorphic forms and patterns help to alleviate tension and promote relaxation. The organic, flowing shapes can contribute to mental well-being by creating a relaxing and soothing environment.

- **Material Connection with Nature:** The integration of natural materials and the incorporation of natural features into the built environment can have a positive impact on occupants' physical and emotional well-being. Natural materials, such as wood, stone, or bamboo, can help to create a warm and tactile environment, which can improve mental health.

- **Prospect:** Incorporating prospect into biophilic design principles improves the built environment in ways that benefit mental health, cognitive performance, and overall well-being. For example, enjoying a view, particularly of nature, has been demonstrated to have a good effect on mood. The visual link to distant scenery promotes feelings of happiness and fulfilment.

- **Refuge:** Incorporating the concept of refuge into biophilic design principles helps to create settings that priorities mental and emotional health. These areas offer individuals a sense of refuge, safety, and connection to nature, resulting in a healthier and more supportive environment.

- **Risk:** Integrating biophilic principles of design into the built environment strives to create environments that promote health while also mitigating risks to health. Biophilic design promotes overall well-being by providing spaces that are aesthetically pleasant, emotionally supportive, and encourage a healthy lifestyle.

➢ SDG 4 - Quality Education

There are ways in which introducing biophilic components into educational facilities might improve the learning experience. Quality Education is related to only a few Biophilic Design concepts and is illustrated below.

- **Visual Connection with Nature:** Natural environments has been linked to increased concentration and cognitive performance. Incorporating visual connections with nature into educational environments can help students maintain focus and boost creativity, resulting in a more productive educational experience. Biophilic architecture can also inspire teachers to create innovative and engaging lesson plans.

- **Thermal & Airflow Variability:** Well-regulated thermal and ventilation conditions improve the physical comfort of students and educators, boosting general well-being and focus.

- **Risk:** Biophilic design principles can be integrated in order to ensure that educational facilities are safe. Educational facilities can become more favorable for learning while minimizing risks.

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

➢ SDG 5 - Gender Equality

There is no direct interconnection between Biophilic Design Principles and Gender Equality Goal

➢ SDG 6 - Clean Water and Sanitation

The relationship between Sustainable Development Goal 6 "Clean Water and Sanitation" and biophilic design principles is primarily based on biophilic design's ability to contribute to sustainable water management, sanitation practices, and the creation of healthy, water-efficient environments. This goal is directly related to the two biophilic design principles: the presence of water and risk.

- **Presence of water:** The inclusion of water in biophilic design principles helps to create surroundings that are visually appealing, emotionally rewarding, and promote well-being. While the direct impact on clean water and sanitation may vary, water features' aesthetic, educational, and therapeutic aspects can be aligned with SDG 6's overall objectives.
- **Risk:** Biophilic design can be integrated with environmentally friendly sanitation solutions, such as water-saving plumbing fittings and on-site treatment systems. This reduces consumption of water, promotes responsible sanitation behaviors, and reduces the dangers associated with water scarcity.

➢ SDG 7 - Affordable & Clean Energy

The relationship between Sustainable Development Goal 7 (SDG 7) on Affordable and Clean Energy and biophilic design concepts focuses upon developing physical environments that improve energy efficiency, encourage renewable energy solutions, and contribute to a sustainable and resilient energy future. SDG 7 is related with the following biophilic design principles:

- **Visual Connection with Nature & Presence of Water:** Biophilic Design can indirectly support the development and deployment of affordable and clean energy technologies, by reducing the overall demand for energy and the associated greenhouse gas emissions.
- **Thermal & Airflow Variability:** Biophilic design principles promote energy-efficient solutions while reducing dependency on traditional heating and cooling systems. By leveraging natural ventilation, passive solar design, and dynamic building strategies, biophilic design contributes to creating built environments that prioritize clean and affordable energy practices.
- **Dynamic & Diffuse Light:** The inclusion of Dynamic & Diffuse Light in biophilic design corresponds with SDG 7 incorporates energy-efficient lighting practices and minimizes reliance on artificial lighting. By utilizing natural light in the built environment, biophilic design helps to create places that are not only visually appealing and occupant-friendly, but also aligned with desire for economical and clean energy.
- **Connection with Natural Systems:** Integrating a relationship with natural systems into biophilic design enables the use of natural heating and cooling processes while also promoting clean and affordable energy practices. Biophilic design helps to achieve the goal of providing everyone with clean and affordable energy by using natural processes,

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

renewable energy sources, and sustainable design influenced by the natural environment. Connection with natural systems can also include the incorporation of smart building technologies that mimic natural cycles.

- **Material Connection with Nature:** Material Connection with Nature promotes the use of sustainable and renewable building and design materials. Choosing materials with a lower environmental impact, such as recycled or fast renewable resources, is consistent with the overall goal of supporting clean and sustainable energy practices.
- **Risk:** While the primary goal is to promote clean energy, the application of such technologies requires careful evaluation of potential risks, such as maintenance challenges, environmental impact, and the requirement for proper end-of-life component disposal.

➢ SDG 8 - Decent work and Economic growth

Biophilic design contributes to economic growth by improving productivity and reducing absence in the workplace. Studies have shown that workers in biophilic environments are more productive and take fewer sick days than those in traditional workplaces The implementation of these principles contributes to energy efficiency and sustainable practices, aligning with broader economic goals. and competitiveness for businesses and organizations.

Biophilic Design principles illustrated in table above are associated with enhanced job satisfaction and contribute to a positive work environment, which improves overall workplace satisfaction. In biophilic design principles contribute to creating work environments that prioritize employee well-being, comfort, and pleasure. These characteristics, in turn, connect with SDG 8's aims of promoting decent work and supporting economic growth through a healthy and engaged workforce.

Many businesses are already adopting biophilic design into buildings and workspaces. Amazon's Seattle headquarters, for example, has a living wall, natural light, and indoor gardens, whilst Google's offices make use of biophilic components like wood and vegetation. These firms recognize the importance of biophilic design in improving their employees' health and well-being, increasing productivity, and contributing to a more sustainable future.

➢ SDG 9 - Industries, Innovation & Infrastructure

Biophilic principles of design can support SDG 9 by encouraging sustainable, resilient, and innovative approaches in infrastructure, industry, and urban planning. Biophilic design can assist industry and infrastructure projects to achieve a more sustainable and inclusive future. SDG 9 relates to the following biophilic design principles:

Incorporating the biophilic design principles studied in this research within industrial and innovation settings helps to create more engaging, sustainable, and visually appealing environments. They also serve to create sensory-rich spaces that prioritize employee well-being, comfort, innovation, safety and pleasure. Additionally, the implementation of these principles contributes to energy efficiency and sustainable practices, aligning with broader economic goals under SDG 9.

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

➢ SDG 10 - Reduced Inequalities

While biophilic design is primarily concerned with improving well-being and connection with nature, its principles can be applied in ways that help to reduce inequalities by ensuring equal access to nature, green spaces, and the positive effects of biophilic environments for people from all socioeconomic groups. Biophilic design can promote inclusive and universal design principles, considering the diverse needs of all individuals.

Emphasizing the use of locally sourced and affordable natural materials supports SDG 10's goals by promoting economic opportunities in local communities. This strategy ensures that the benefits of biophilic design are not limited to specific socioeconomic groups, which helps to eliminate material inequalities.

➢ SDG 11 - Sustainable Cities and Communities

Biophilic design principles play a crucial role in creating sustainable, resilient, and people-centered cities and communities. Cities that prioritize nature in urban planning and design, cities can address environmental challenges, improve quality of life, and contribute to the achievement of SDG 11.

- **Visual Connection with Nature:** Fostering visual connection with nature in urban architecture provides cities' and communities' overall sustainability, well-being, and livability. Incorporating these biophilic design principles can make urban spaces more harmonious and visually appealing.
- **Non-visual connections with nature, Non-rhythmic sensory stimuli and Dynamic & Diffuse Light:** In urban design improves the entire sensory experience of cities, which contributes to citizens' well-being and pleasure. By adopting these biophilic design principles, urban areas can become more engaging and conducive to a comprehensive urban living experience, in line with SDG 11's objectives.
- **Thermal & Airflow Variability and Dynamic & Diffuse Light:** are incorporated in creating urban environments that prioritize human comfort, energy efficiency, overall well-being and creating environments that respond to the local climate.
- **Presence of water and Material connection with natural**: in urban areas contributes to create sustainable, visually appealing, and socially inclusive cities and communities. Water features promote the quality of urban life, stimulate biodiversity, and help to create lively, resilient, and water-responsive urban settings.
- **Biomorphic Forms & Patterns and complexity and order:** designs inspired by nature's forms can improve the aesthetic of urban areas, increase well-being, and provide a sense of harmony with the environment. In addition to fostering a sense of order, functionality, with the natural world.

➢ SDG 12 - Responsible Consumption and Production

Responsible Consumption and Production aims to ensure sustainable practices for the way consume products and resources are produced. While the key objectives of SDG 12 are to reduce waste, promote resource efficiency, and encourage sustainable lifestyles, there are links between biophilic design principles and responsible consumption and production.

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
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- **Visual Connection with Nature:** Biophilic principles of design may affect consumer behaviour, inspire ethical decisions, and help to promote a more sustainable approach to consumption and production. Designers and businesses can help promote ethical consumption habits by developing places that visually connect people to nature.
- **Non-visual connections with nature**: involves auditory, olfactory, tactile, and thermal experiences, and can contribute to responsible consumption and production patterns
- **Thermal & Airflow Variability:** This approach focuses on designing environments that mimic the natural variations in temperature and airflow found in natural settings. It also helps to promote responsible consumption and production practices by decreasing dependency on artificial heating and cooling systems and optimizing the use of natural climatic conditions.
- **Presence of Water:** By integrating water-efficient technologies, fostering awareness, and creating environments that respect water as a precious resource, biophilic design contributes to the broader objectives of sustainable and responsible resource use and promote responsible water consumption and production practices.
- **Dynamic & Diffuse Light:** Incorporating Dynamic & Diffuse Light biophilic design concepts promotes SDG 12 by supporting energy-efficient lighting solutions, improving occupant well-being, and lowering the environmental impact of artificial lighting.
- **Connection with Natural Systems, Biomorphic Forms & Patterns and Material Connection with Nature:** promote a symbiotic interaction between human activities and the environment. These principles help to promote responsible consuming practices and the ultimate objective of sustainable and regenerative resource usage by encouraging a greater understanding of ecological processes and embracing nature-inspired design.
- **Complexity & Order:** Creating well-ordered and optimized spaces, products, and systems, these principles encourage responsible consumption and production practices, aligning with the broader goals of sustainable development.

➢ SDG 13 - Climate Action

Biophilic design can help mitigate climate change by reducing energy consumption and greenhouse gas emissions, as well as increasing the resilience of buildings and infrastructure to climate-related risks.

- **Visual Connection with Nature:** in urban environments, contributes to create t green spaces, natural landscapes, and visible vegetation, can serve as reminders of the importance of preserving natural ecosystems and combating climate change. By integrating visual elements of nature into urban design, awareness of environmental issues can be heightened, supporting efforts to address climate change.
- **Thermal & Airflow Variability and Dynamic & Diffuse Light:** are incorporated in creating urban environments that prioritize human comfort, energy efficiency and creating environments that respond to the local climate.

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
Online ISSN 2805-2846

- **Presence of Water:** incorporating water features such as ponds, rain gardens, and green infrastructure in urban design can help mitigate the impacts of climate change. Water elements can contribute to natural cooling, stormwater management, and biodiversity, enhancing the resilience of urban areas to climate-related challenges.
- **Connection with Natural Systems and Biomorphic Forms & Patterns:** Natural systems play a crucial role in carbon sequestration, helping to mitigate greenhouse gas emissions and combat climate change. Urban green spaces and vegetated areas contribute to carbon storage, thereby supporting the objectives of SDG 13 by reducing the urban carbon footprint and enhancing climate stability.
- **Material Connection with Nature:** Natural materials, such as timber and natural fibers, have the potential to store carbon and mitigate greenhouse gas emissions. By incorporating these materials into urban infrastructure and buildings, cities can contribute to carbon sequestration efforts, aligning with the objectives of SDG 13 by reducing the carbon footprint of urban development.
- **Complexity & Order:** Applying principles of complexity and order to resource management supports the goals of SDG 13. Efficient and well-organized resource utilization, including energy, water, and materials, can contribute to reducing greenhouse gas emissions and promoting sustainable practices in urban environments.

➢ SDG 14 - Life Below Water

Biophilic Design may not directly contribute to this goal, it can indirectly support it by promoting sustainable resource use and reducing negative environmental impacts. For example, Biophilic Design can incorporate sustainable building materials, such as recycled or renewable materials, to reduce the use of virgin materials that may contribute to ocean pollution. Additionally, Biophilic Design can promote sustainable practices, such as reducing water consumption and runoff, which can indirectly support SDG 14 by reducing the negative impacts of human activities on the oceans and marine life.

SDG 15 - Life on Land

Biophilic design encourages the use of natural materials, sustainable landscaping practices, and the integration of ecological processes within urban areas. This approach supports the goal of promoting sustainable land use and minimizing the environmental impact of human activities on land, aligning with the objectives of SDG 15. the following table shows that the relationship between this SDG and biophilic design principles is the strongest one.

➢ SDG 16 - Peace, Justice and Strong Institutions

There is no direct interconnection between Biophilic Design Principles and Peace, Justice and Strong Institutions.

➢ SDG 17 - Partnerships for the Global

There is no direct interconnection between Biophilic Design Principles and Partnerships for the Global Goal.

Art and Architecture Journal
Volume 4, Issue 1, p 252 - 272
Print ISSN 2805-2838
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6- Results and Conclusions

(Table 4) Demonstrates the interrelationship between biophilic design principles and Sustainable Development Goals (SDGs). The different colour shades indicate the degree of relevance of biophilic design contributions to the different SDGs, with the grades marked from the lowest one (The Orange Shade) and in the middle (The Yellow Shade) to the highest (The Green Shade).

The comparative analysis of these two issues, we find that the multiform benefits of biophilic design address diverse challenges in sustainable architecture. The ranking of contribution relevance shows that four of the seventeen SDGs (SDG 3, SDG 9, SDG11 and SDG 13) are heavily supported by biophilic design principles, and four SGDs (SDG 7, SDG 8, SDG 12 and SDG 13) also directly take advantage from biophilic design in many cases. In contrast, six SDGs (SDG 1, SDG 2, SDG 4, SDG 6, SDG 10 and SDG 14) generally only benefit from biophilic design's indirect contributions. Examples include developing urban agriculture to produce food for SDG 2 Zero Hunger, conducting appropriate water management to reduce pollution for SDG 14 Life Below Water, and more. Although biophilic design has limited effects in pursuing these goals, the exploration of indirect benefits provides additional insights for understanding the notion of sustainable architecture. As follows (Fig. 7) refer to how many SDGs can biophilic design principles achieved it. Although, the benefits could be measurable, not directly measurable, quantifiable, unquantifiable, tangible, and intangible. Many of these principles are interrelated, although they are discussed from different standpoints. For instance, the proper use of indigenous natural materials cannot only reduce construction costs to reduce poverty (SDG 1) but also contribute to the recycling of materials for more responsible consumption (SDG 1). Reducing air pollution provides environmental benefits and is also related to optimizing indoor air quality in health. Additionally, from the challenge-benefit analysis, some priorities (e.g. air, daylight, plants, and landscape) in biophilic design are uncovered in achieving multiple sustainable goals. Facing climate change, we need to explore more solutions with benefits for sustainable architecture. Therefore, more qualitative and quantitative research is required to identify biophilic design strategies and guidelines in developing efficient solutions and support the enactment of criteria.

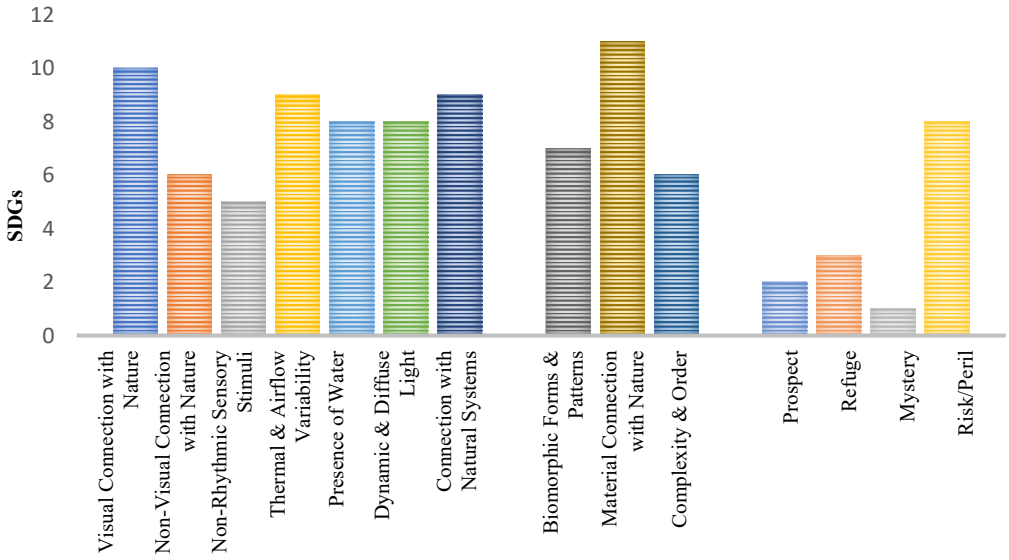

Fig. 7 – The Integration Results (Author).

Art and Architecture Journal
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