Architecture

DOI: 10.23968/2500-0055-2024-9-1-3-16

BIOPHILIA IN THE WORKPLACE: A PILOT PROJECT FOR A LIVING WALL USING AN INTERACTIVE PARAMETRIC DESIGN APPROACH

Ayman Assem*, Doaa K. Hassan

Architectural Engineering Department, Faculty of Engineering, Ain Shams University, Egypt

*Corresponding author's e-mail: ayman.assem@eng.asu.edu.eg

Abstract
Introduction: Workplace outcomes are significant not only for productivity and profitability but also for the value of the process and the experience elements involved in reaching these objectives. There is a continuous discussion between employers and employees regarding the concept of the workplace, concentrating on a thorough understanding of labor and its physical surroundings. This study focuses on the connection with the natural world, specifically how plants can improve aesthetics and support well-being in the built environment. The study explores the implementation of biophilic design to combat sick-building syndrome by integrating a living wall into workplace interiors. **Methods:** The study employs a parametric design approach to identify a design solution for incorporating a living wall into the workplace. This approach optimizes the correlation between multiple parameters influencing the design outcome. This approach operates on two levels: firstly, an analogical design process is employed to establish the form of green wall units and generate various iterations based on generation parameters derived from the natural concept source. Secondly, interactivity is incorporated to enhance users' perception of the green wall and its different states, ultimately leading to the creation of a unique ambiance suitable for diverse functions or activities within the space. **Results:** The results section would detail the specific outcomes of employing the parametric design approach, including the successful establishment of green wall units' forms, the generation of various iterations, and the enhancement of user perception through interactivity. The effectiveness of these design solutions in creating a unique ambiance and optimizing user engagement within the workplace is presented.

Keywords: biophilia, parametric design, green wall, interactive design.

Introduction

What makes a working experience good? Nowadays, thanks to modern organizations and their employees, it is not only about the end goal of productivity and profit, but also about the process and the experience itself in reaching the goal. By understanding the importance of the process, it will be easier to fix, enhance, and modify it for a better outcome. Then, the workplace is gaining meaning, while ensuring well-being and a sense of purpose. The definition of the workplace is still a matter of debate. Employers and employees are engaging in this debate about taking a more holistic view of work and the workplace, and the role they play in our daily lives. In this sense, a connection with nature becomes a significant part of such discussions (Browning and Cooper, 2015).

Natural settings have a crucial well-being and restorative impact (Gunawardena and Steemers, 2019). In this sense, the growing academic and organizational interest in biophilic design, regarding the positive outcomes for individuals and businesses, is driving more studies and applications in this area. The timing behind this growing interest lies in the broader socio-historical context of the movement of populations from rural to urban environments. We are as disconnected from nature as we have ever been (Browning and Cooper, 2015). Biophilia is an innate urge of people to connect with nature and other forms of life and life-like processes. In fact, biophilia is an integral part of human development, both physically and mentally. Therefore, people are always looking for opportunities to experience nature outside of urban areas and even within them.

Then, integrating biophilic environments in workplaces can provide employees with psychologically restorative experiences by alleviating mental fatigue and reducing their levels of stress. In this respect, it is important to understand the components and characteristics of biophilic design. A number of studies in this area resulted in 14 patterns for biophilic design. The patterns were confirmed by intensive studies, the works of Christopher Alexander, Judith Heerwagen, Rachel and Stephen Kaplan, Stephen Kellert, Roger Ulrich, and many others, as well as considerable multidisciplinary study. These 14 patterns are intended to be flexible and adaptable, offering a wide range of possibilities for both indoor and outdoor spaces. These patterns are classified under three main categories: nature in

For citations: Assem, A., Hassan, D. K. (2024). Biophilia in the workplace: A pilot project for a living wall using an interactive parametric design approach. Architecture and Engineering, No 1 (9), pp. 3–16. DOI: 10.23968/2500-0055-2024-9-1-3-16.

the space patterns, natural analogues patterns, and nature of the space patterns (Downton et al., 2017). The first category includes: (1) visual connection with nature; (2) non-visual connection with nature; (3) non-rhythmic sensory stimuli; (4) thermal and airflow variability; (5) presence of water; (6) dynamic and diffuse light; (7) connection with natural systems. The second category includes: (8) biomorphic forms and patterns; (9) material connection with nature; (10) complexity and order. The third category includes: (11) prospect; (12) refuge; (13) mystery; (14) risk/peril. The patterns of (10) complexity and order; (13) mystery; and (14) risk/peril have far less published material available on this topic (Peters and D'Penna, 2020).

In this sense, adopting plantation in terms of green surfaces is the most commonly used method to blend with nature. Including plant life has been identified to increase positive distractions and emotions, promote restoration from illness and stress, and enhance the socio-cultural climate. This impact is a result of the dynamic experience that plants add to spaces, creating a comprehensive sensory ambiance. The contribution of plants to the aesthetic and well-being enhancement is acknowledged in built environment discourse as biophilic design, in response to the need to alleviate symptoms of sick-building syndrome (Gunawardena and Steemers, 2019). In addition, surface greening has received much attention, particularly in cities with dense morphologies, as a response to the call for encouraging passive approaches such as green infrastructure (Assimakopoulos et al., 2020). Therefore, this research is examining the biophilic potential of living walls in terms of their ability to address the 14 patterns.

Literature review

Building exteriors, including their walls and roofs, have been greened for centuries. For the past 2,000 years, climbing plants have been positioned in traditional architecture at the base of building facades or planter boxes to blend with the building elevations. The adoption of vertical greening, which integrates vegetation and buildings, has a significant impact on enhancing indoor and outdoor climates, aesthetics, insulation, reducing greenhouse gas emissions, and increasing ecological values (Sheweka and Magdy, 2011). In various climatic conditions, vertical greening can be used as an indoor or outdoor system (with the aid of natural or artificial lighting). Depending on the geography and environment, different plants and soils are selected. There are numerous vertical greening techniques available today that fall under the categories of green facade and living wall, which have similarities and important differences. Overall, forms of vertical greening can be defined as follows (Rakhshandehroo et al., 2015) (Fig. 1):

- Green facades (predominantly seen as exterior applications) are essentially vertical trellises or framework constructions that hold plant branch systems. These systems are positioned at the base of the building facades, in pots at the base of the framework, or in floating containers attached at regular intervals to the facade frame (Gunawardena and Steemers, 2019; Radić et al., 2019).
- Living walls (for exterior and interior applications) are structures with soil or another growing medium distributed over their surface or volume. Plants grow on them or have their root systems in them (Gunawardena and Steemers, 2019; Radić et al., 2019).

Whatever the approach, both green facades and living walls share many similar attributes and values (Lundegren, 2016; Sheweka and Magdy, 2011):

- Enhancement of aesthetic appearance and design.
- Affective bonds and well-being.
- Sound reduction and buffering.
- Climate regulation that generally occurs through insulation, which helps keep the cold out in winter and the interior cool in the summer. In other

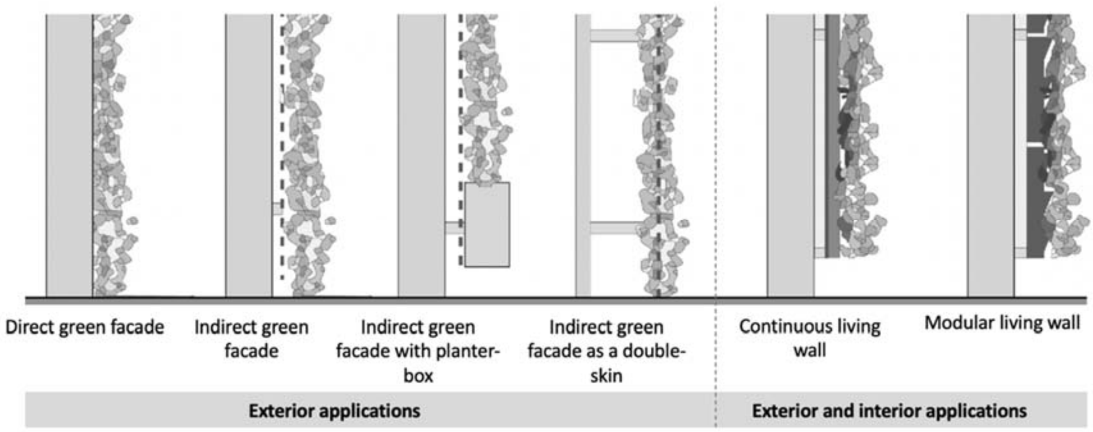

Fig. 1. Vertical greening categories (Gunawardena and Steemers, 2019)

words, summertime cooling involves less heat gain and evaporative cooling, while winter requires insulation and a wind barrier.

- Air filtration and better air quality (by reducing greenhouse gases such as carbon dioxide (CO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2)).
- Possibilities for edible and medicinal plants and habitats for wildlife.

Our research focuses on the living wall system as a means of enhancing workplace interiors through the adoption of biophilic design patterns. Therefore, based on the patterns in the introduction section, nature in space and natural analogs will be the main focus in this regard. The phrase “nature in the space” addresses the immediate, tangible, and transient presence of nature. In addition to winds, noises, smells, and other natural elements, this also includes living things such as plants, water, and animals. Direct connections with these natural elements, particularly through diversity, mobility, and multi-sensory interactions, can lead to the most powerful spatial experiences. Natural analogs, on the other hand, deal with biological, non-living, and indirect evocations of nature. It is possible to use items, materials, colors, shapes, patterns, and arrangements found in nature to create artwork, decorations, furniture, and textiles for the built world. Contrary to the previous two methods, nature of space is concerned with the spatial configuration of spaces, which goes beyond the focus of adopting vertical greening as a single element. Therefore, the patterns related to the first two methods will be applied in this research (Downton et al., 2017).

Accordingly, it can be inferred that such designs incorporate many interrelated factors to optimize the solution. Then, a parametric design approach could be beneficial in this respect. A previous pilot study attempted to address the issue of separating parking garages from nature and urban connectivity by designing a combination facade and living and habitat wall systems. This design was created to measure and optimize aesthetics, temperature gradients, water supply, air quality, habitat, and cost. The final project demonstrated environmental benefits and costs associated with a combination of living wall and synthetic habitat technologies through the use of building information modeling (BIM) and other parametric design software (Briscoe, 2014). This pilot predicted the role of computation in understanding trends of migration and succession. Another pilot study emphasized that this parametric design makes it easier for designers to modify their work and create their own algorithms, resulting in a more effective way of designing and producing the final output. It was about designing interior panels using parametric modeling tools. This pilot study focused on reducing time consumption and eliminating unnecessary steps in the traditional process, while also taking into account the changeable and adaptive geometries (Kim et al., 2016). Accordingly, this research aims to parametrically design a responsive living wall in a workplace interior, adopting a biophilic design approach to maximize the efficiency of users' experience.

Methodology

This research is based on a pilot study that was completed as a primary requirement for a postgraduate course titled “Interactive and Responsive Architecture”. Postgraduates were required to parametrically design an interior living wall in a workplace to enhance employees' performance through the physical settings of the interior environment, adopting biophilic design. The parametric design process will be adopted to optimize the interrelation values of the different parameters that affect the design product at two levels: analogical design and configuration, and interactivity.

Pilot description: design and configuration

The pilot description is presented in terms of the phases of the design process and the targeted attributes of the product as follows:

- Parametric analogical design;
- Technical installations;
- Interactivity with reference to both plants' and users' needs;
- Fabrication and implementations.

To achieve the pilot goal, specific characteristics for the final product were designated to be analogical design-based, modular, and interactive to maximize the value of biophilic design. The patterns are applied as follows (Table 1):

Parametric analogical design process

In design, analogies are often used to solve problems. Since the design process is viewed as an exploratory activity based on visual thinking, the use of visual representation by analogy is considered a powerful creative problem-solving strategy. Accordingly, analogical thinking enables designers to find similarities between a target design space and an existing knowledge base and translate that existing knowledge into new design solutions (Kaumoodi, 2021).

The configuration of a living wall depends on specific parameters, such as using analogy as a source of idea generation, considering plantation aspects (including plant types, growth medium, irrigation, energy, and lighting), and utilizing new technology materials and fabrication.

In our concept, analogy as a source of idea generation was inspired by the following (Fig. 2):

- Form of specific fruits, such as pineapples, pine cones, and much more in a natural shape design.
- Structure of plant leaves.

The modular living wall design was developed to produce two design proposals: one for the overall

Table 1. **Proposal for the implementation of merging patterns in interior living wall systems**

	Patterns	Definitions	Application
Nature in Space	Visual connection with nature	A view of the environment, including living things and natural processes.	•
	Non-visual connection with nature	Stimuli that evoke a positive association with nature, living things, or natural processes through auditory, tactile, olfactory, or gustatory means.	•
	Non-rhythmic sensory stimuli	Connections with nature that are stochastic and transient and can be statistically examined but may not be precisely predicted. (Movement and sensory effects are inherently brief — no more than 20 seconds every 20 minutes. For example, the flight of a butterfly or the journey of a cloud, or a simple shifting of light throughout the day.)	
	Thermal and airflow variability	Variations in the skin airflow, relative humidity, and temperature.	
	Presence of water	Participation that enhances a location's experience through seeing, hearing, or touching water.	
	Dynamic and diffuse light	Uses shifting light and shadow intensities that fluctuate over time to mimic natural conditions.	•
	Connection with natural systems	Understanding of natural processes, particularly the seasonal and temporal fluctuations that characterize a thriving ecosystem.	
Natural Analogs	Biomorphic forms and patterns	Figurative allusions to naturally occurring curved, patterned, textured, or numerical arrangements.	•
	Material connection with nature	Minimally processed natural materials and components that represent the area's environment or geology and contribute to a strong sense of place.	
	Complexity and order	understanding of natural processes, particularly the seasonal and temporal fluctuations that characterize a thriving ecosystem. (A place with good complexity and order feels interesting and information-rich, striking an intriguing balance between being dull and overwhelming.)	•

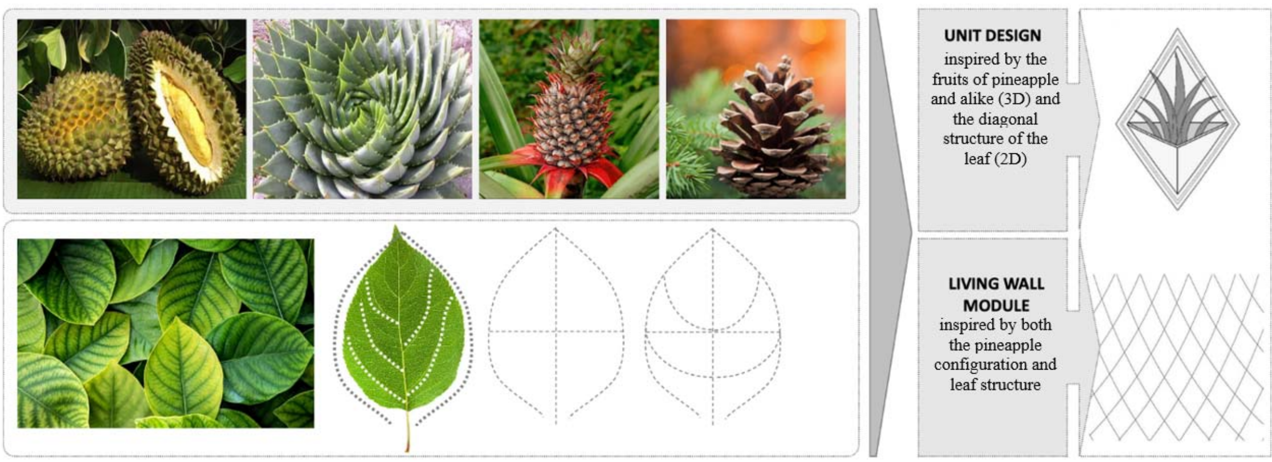

Fig. 2. Unit and living wall module: analogical design

wall to function as a unified whole, and another for the unit to function as an independent entity.

As previously mentioned, the parametric design approach was employed to enhance the interrelation of many parameters that impact the design result. This optimization occurred at two levels, namely analogical design and configuration, as well as interactivity, which are further elaborated upon in subsequent sections.

The applied parametric analogical design process (Fig. 3) consisted of five sequential processes. It began by selecting a source of inspiration derived from natural elements. Subsequently, a visual analysis was conducted to emphasize the primary design features, visual principles, and rules for creating shapes. The next phase involved converting these constituent components into design parameters, which define the primary design elements, spatial arrangements, distances, forces, and other quantitative aspects. The fourth phase involved constructing the model algorithm using parametric design software. In our pilot study, we used the Grasshopper plugin to develop the algorithm. This process resulted in the creation of many model iterations.

A. Living wall as a unified modular system

The living wall was constructed using a module system that was developed through a parametric design method, as previously mentioned. This modular system comprises multiple levels: 1. The base grid establishes the cellular modules of the planting pots and the structural framework system. 2. The steel structure mesh, which serves as the primary mounting system for the green wall. 3. The LED lighting lines. 4. The layer for the fixation of plant pots. 5. The empty fabricated pots. 6. Lastly, the soil and the planting process (Figs. 4 and 5).

B. Independent unit design (separate unit)

The concept of separate unit design involves the development of a unit that operates autonomously with respect to all of its systems (Fig. 6). The aggregation of the cells has the potential to display various designs and encompass diverse wall areas. Furthermore, it can be installed as a unified cell unit. The adaptable nature of this design enables it to meet various requirements of both humans and plants, while also being suitable for any given spatial constraints.

Technical installations

This section covers the technical aspects related to plantation and water management systems, as outlined below:

A. Indoor plant types and requirements

Plants are the primary and fundamental elements of living walls. Particular types of plants are selected to fulfill the intended design objectives. Interior living walls typically incorporate a selection of tropical plant species, with a particular emphasis on vining,

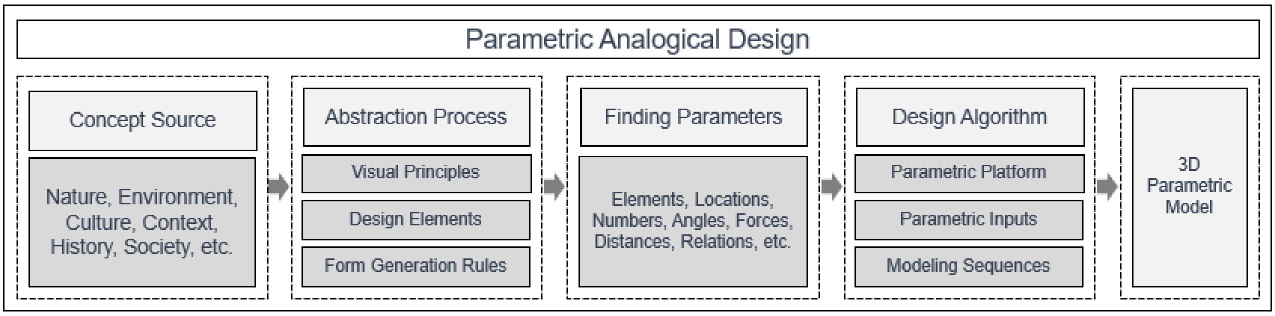

Fig. 3. Process of parametric analogical design

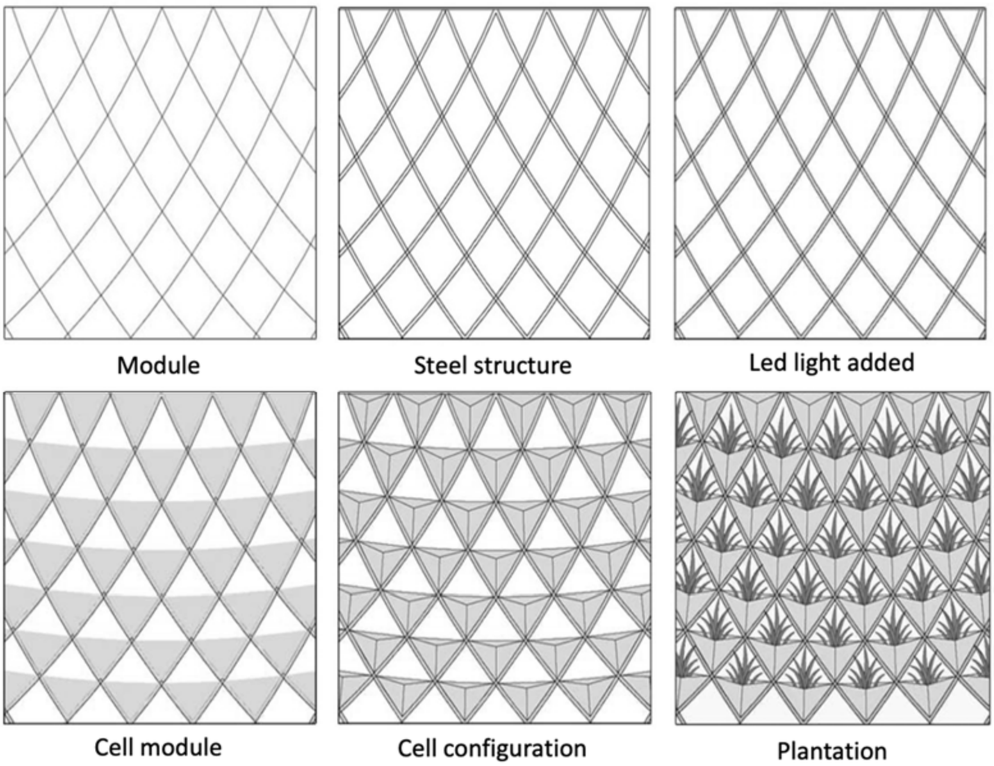

Fig. 4. Living wall design

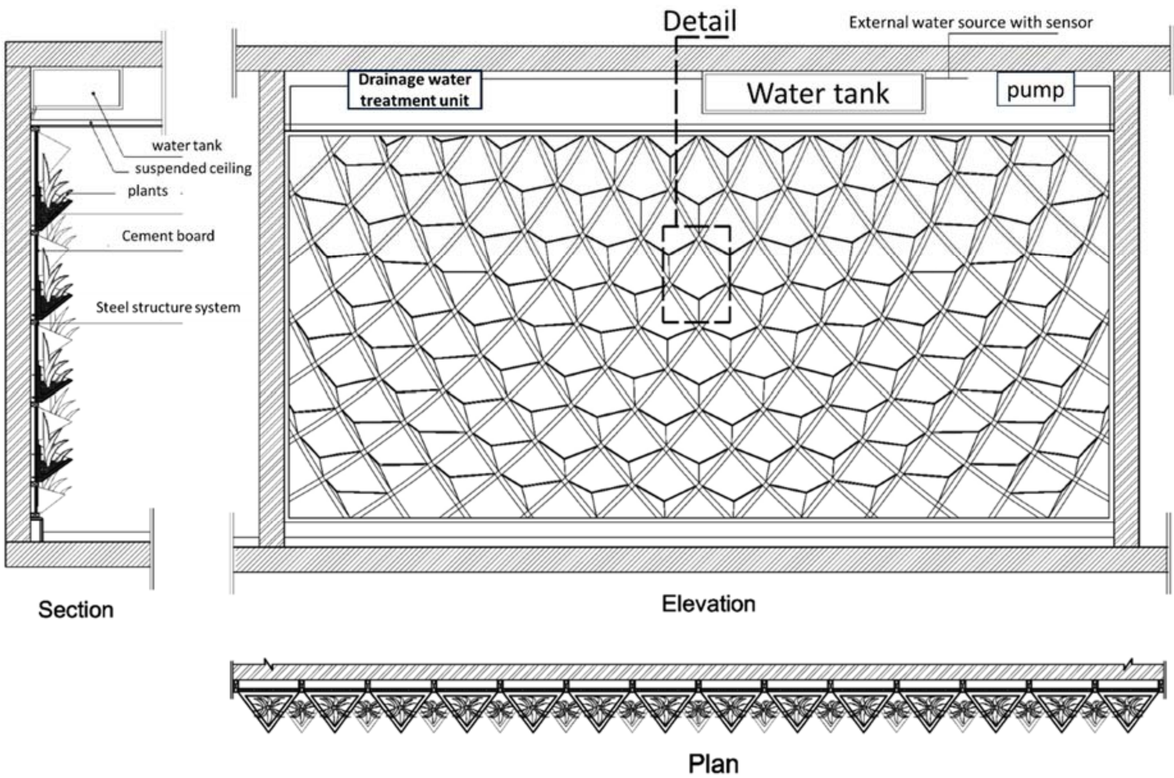

Fig. 5. Living wall detailed drawings

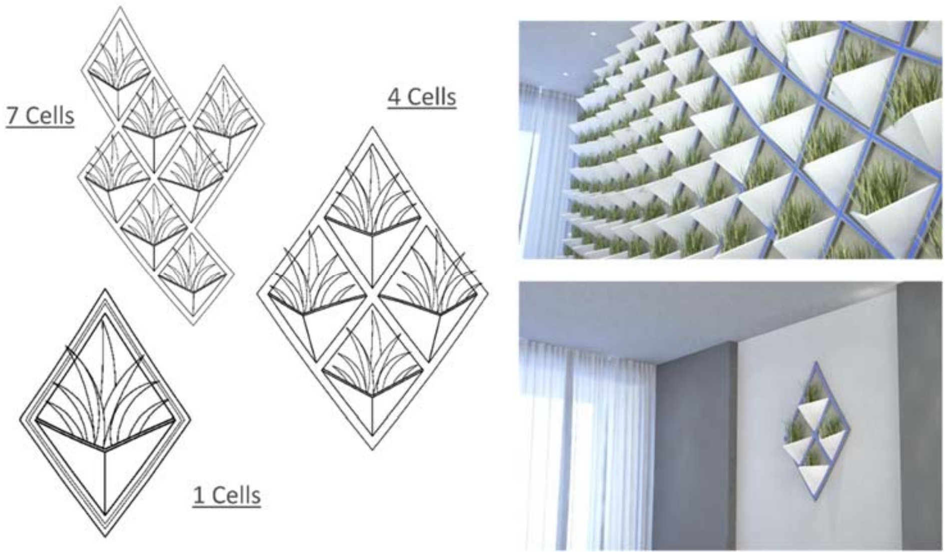

Fig. 6. Independent cell design and its various distributions

climbing, and fern varieties. Vertical gardens are a popular choice for cultivating a diverse array of attractive plant species. Specifically, a total of thirty-two species, including *Asplenium thunbergii*, *Alocasia sanderiana*, *Anthurium crystallinum*, *Anthurium andraeanum*, *Aeschynanthus radicans*, *Chlorophytum bichetii*, *Cercestis mirabilis*, *Caladium lindenii*, and *Epipremnum aureum*, are usually selected for this purpose (Sarkar, 2018). The Table 2 presents a comparison of different species of indoor plants that can be included in biophilic design settings.

Based on the comparison table above, the selection of Pothos (*Epipremnum aureum*) and Lipstick plant (*Aeschynanthus radicans*) for biophilic interior designs is justified because of their distinctive attributes that align with the concepts of enhancing indoor environmental quality and psychological well-being. The Pothos plant is highly efficient at enhancing indoor air quality and is capable of tolerating different lighting conditions and irregular watering. This makes it a suitable option for indoor plant care and air purification. The Lipstick

Table 2. **Comparison of indoor plant species for integration in biophilic design settings**

Scientific Name	Light Requirements	Watering & Humidity	Growth & Appearance	Special Features
Asplenium thunbergii (Thunberg's Spleenwort)	Partial to full shade	Moist but well-drained	Delicate fronds, prefers shaded environments	Often used in terrariums, good for shaded gardens
Alocasia sanderiana (Kris plant)	Bright, indirect light	High humidity, regular watering	Large, arrow-shaped leaves with white veins	Striking foliage, prefers warm and humid environment
Anthurium crystallinum (Crystal anthurium)	Bright, indirect light	Regular watering, high humidity	Heart-shaped leaves with white veins	Popular for decorative indoor use, needs warm environment
Anthurium andraeanum (Flamingo flower)	Bright, indirect light	Regular watering, enjoys humidity	Bright spathes and contrasting spadices	Often used in floral arrangements, ornamental
Aeschynanthus radicans (Lipstick plant)	Bright, indirect light	Consistent moisture, prefers humidity	Trailing vines with tubular flowers	Great for hanging baskets, attractive blooms
Chlorophytum bichetii	Bright, indirect light	Regular watering, tolerates average humidity	Arching leaves, grass-like appearance	Easy to care for, works well in various indoor settings
Cercestis mirabilis	Partial to full shade	Moist, well-drained soil	Large, heart-shaped leaves	Unique foliage, adaptable to indoor conditions
Caladium lindenii (Xanthosoma lindenii, Angel's Wings)	Bright, indirect light	Consistent moisture, high humidity	Arrow-shaped leaves with white veins	Eye-catching foliage, sensitive to cold temperatures
Epipremnum aureum (Pothos)	Low to bright, indirect light	Can tolerate irregular watering, average humidity	Heart-shaped variegated leaves	Air-purifying, extremely adaptable to indoor conditions

plant, characterized by its vivid, tubular flowers and preference for strong, indirect light, offers both visual appeal and psychological benefits, crucial for creating compelling and emotionally nurturing spaces. Incorporating these plants into indoor spaces enhances their visual appeal and promotes a healthier and more harmonious living environment, aligning with the core principles of biophilic design that emphasize the connection between nature, human well-being, and the built environment.

1. Lipstick plant (*Aeschynanthus radicans*)

The Lipstick plant, known for its climbing nature, exhibits a visually captivating appearance, particularly when it is allowed to gracefully drape from suspended containers. The plant has aesthetically pleasing, succulent foliage that remains green throughout the year, accompanied by the production of visually striking, crimson tubular blossoms. The growth of Lipstick plants is a rather uncomplicated process. The plant can be cultivated in both indoor and outdoor environments. Additionally, due to its minimal soil requirements, it can be successfully grown on vertical surfaces. The optimal conditions for the growth of the Lipstick plant pertain to its chosen substrate, which includes consistently moist, nutrient-rich, and well-drained soil. It is recommended to mix light, sandy soil with either humus or peat moss. The presence of peat moss in this mixture ensures that the humidity level is consistently optimized. During this period, the sand will provide sufficient drainage to prevent the occurrence of root rot. The ideal environmental conditions for the Lipstick plant involve exposure to bright, dappled light. Adequate illumination is necessary for its optimal growth and development. It is advisable to avoid exposing the plant to direct sunlight or complete darkness in its placement. The replication of a plant's natural environment can be achieved when it is kept indoors by using artificial lighting. Both fluorescent and LED lighting can be used without any issues. The objective is to select hues that lean towards the cooler end of the color spectrum, resembling the chromatic palette observed on a sunlit day with accompanying shadows. The daily requirement for exposure to light is limited to three hours (Johnstone, 2022) (Fig. 7a).

2. Pothos (*Epipremnum aureum*)

The NASA/ALCA study on the use of common indoor plants for interior air purification designates Pothos as one of the top three plants with the commendable attribute of being an exceptional air-cleansing plant. *Epipremnum aureum*, also known as the golden pothos, exhibits aesthetically pleasing marbled leaves and possesses a resilient nature, requiring less maintenance. Consequently, it has gained significant popularity as a choice for indoor plants. One notable attribute of this plant is its ability to thrive in a hydroponic environment, such as a water-filled bottle or a soilless container. Even direct sunlight is not required. The plant has tolerance for bright light; however, optimal results are achieved when it is exposed to medium indirect light. Regular watering is necessary during the spring to fall seasons, while caution should be exercised to avoid excessive irrigation during the winter months. The optimal growth conditions for the plant are a combination of arid topsoil and warm, sunny temperatures. Sandy loam and clay soils are considered optimal for the growth of this particular species (Meshram and Srivastava, 2015) (Fig. 7b).

B. Growth medium

One of the primary concerns at hand pertains to the composition of the growing media, which plays a crucial role in facilitating the growth of plants and the formation of infrastructure. The growing medium should provide the essential needs of the plants, including water and air. When designing a living wall, it is important to take into account additional factors such as weight, durability, and stability. Based on the aforementioned rationales, it can be concluded that soilless culture is the optimal choice for implementing a living wall (Tamási and Dobszay, 2015).

Soilless culture refers to the practice of cultivating plants in the absence of traditional soil-based mediums. The use of traditional soil poses unique challenges, including the difficult and expensive management of soil-borne pests and diseases, salinity issues, insufficient fertility, and limited water availability. In contrast, soilless culture offers numerous advantages compared to conventional agricultural methods. These include the ability to obtain high-quality yields, exert control over root environments, optimize water utilization, cultivate crops regardless of unfavorable soil conditions, and mitigate the presence of weeds and soil-borne illnesses. Soilless cultures can be classified into two primary categories:

1. Substrate culture:
- Organic (peat moss, wood residues, rice hulls, etc.);
- Inorganic (perlite, sand, vermiculite, pumice, calcined clays, etc.) (Almusaed, 2011).
2. Water culture.

Numerous studies indicate that inorganic materials are often favored as the primary material due to their superior stability and durability compared to organic growing media. Nevertheless, when evaluating the desirable attributes of plant growth media, it is evident that many physical and chemical aspects of inorganic growing media are comparatively inferior to those of organic growing media (Dede et al., 2019). Peat moss has been selected as the organic substrate culture in this pilot due to (Espiritu, 2022):

- Absorbency. Peat moss retains water much better than average soils.
- Compaction. It does not compact, unlike other organic materials. Soil compaction is damaging to gardens and reduces water absorption and plant growth. Peat moss remains springy when it is wet and rehydrates easily. Plus, one application of peat moss can last for years.
- Sterile planting medium. This means that it does not contain harmful pathogens or weed seeds. This, combined with its absorbency, makes it ideal for starting seedlings, which is why peat moss is an essential component in most seed starting mixes.
- Acidic pH. Acid-loving plants benefit greatly from peat moss applications.

C. Water management systems

In order for plants to undergo growth, they require the essential elements of water, light, and nutrients. Fulfilling these requirements is made easier with the implementation of an irrigation system. The effectiveness of irrigation systems depends on various factors, including spatial considerations, the type of crops being cultivated, and the associated expenses for both indoor and outdoor installations. When considering the cultivation of indoor plants, it is essential to address seven key components to establish an irrigation system that adequately caters to the plants' requirements. These components include selecting appropriate growing media, providing a sufficient water supply, establishing effective irrigation channels, implementing proper

a) b)

Lipstick plant (*Aeschynanthus radicans*) (Johnstone, 2022)

Pothos (*Epipremnum aureum*) (Wikimedia Commons, 2022)

Fig. 7. Used indoor plants

drainage mechanisms, providing essential nutrients, identifying suitable energy sources, and using appropriate light sources. This section provides an analysis of the requirements and their implementation within the pilot study (Figs. 8 and 9).

The quantity of water is one of the main factors affecting plant quality, and it depends on the type of plant, the season, the orientation of the vertical walls, and the temperature. The pilot irrigation system provides a watering timer to control the amount of water that plants need based on temperature and time. The water is provided using a water tank and pump (Wilkinson et al., 2021).

To distribute the water among the planting units, the irrigation channels are used as a main part of the system. They are usually poly tubing connected on one side to a water supply and on the other side to a vertical wall system, allowing water to drip slowly when placed on top of a vertical green wall. In our pilot, the irrigation channels are hidden, while in others they could be exposed and used as part of the decorative appearance of the system (Madani et al., 2013).

Drainage is an important factor in a green wall system. Effective drainage is necessary to prevent diseases, fungal or bacterial infections, and salt build-up in living wall planters. The drainage process usually occurs when the irrigation channels are sloped to end in a water basin.

In the pilot, an integrated piped system is used in the back of the entire wall, embedded into the steel structure system of the green wall. The water supply path starts from a ceiling-suspended water tank and moves to a water pump in order to control water pressure inside the pipes distributed along all plant cells.

D. Energy and lighting

Indoor vertical green walls require an energy source to facilitate the circulation of irrigation water within the system, as well as to power LED lights. These lights serve a dual purpose by providing plants with the necessary light for photosynthesis and contributing to the aesthetic appeal of the installation.

Interactivity

The concept of interactive interior design pertains to the creation and integration of interactive components within a defined physical environment. Recent advancements in technology have facilitated the emergence of novel applications and engagement opportunities that can be seamlessly linked with the architectural aspects of places (Nabil and Kirk, 2019).

The concept of interactivity in the pilot study significantly influences users' perception of the green wall and its diverse states, ultimately resulting in the creation of distinct atmospheres suitable for various functions or activities within the space.

The design of interactive living walls is addressed through the utilization of various sensors, as outlined below:

- Plant: light and water/irrigation & drainage;
- Users: light mode (color and intensity) related to speech/sound level parameters.

This section examines three primary modes of interaction that are based on the use of three distinct types of sensors capable of detecting three specific categories of inputs: 1) detection of sound levels; 2) detection of soil moisture; 3) detection of light levels.

Fig. 10 illustrates the concept of interactivity related to the three distinct forms of detection. The system will then generate a response and implement the predetermined actions accordingly.

A. Sound detection sensor

The concept of interaction was derived from observing the impact that plants have on human beings. Research findings indicate that the presence of indoor plants has been associated with enhanced

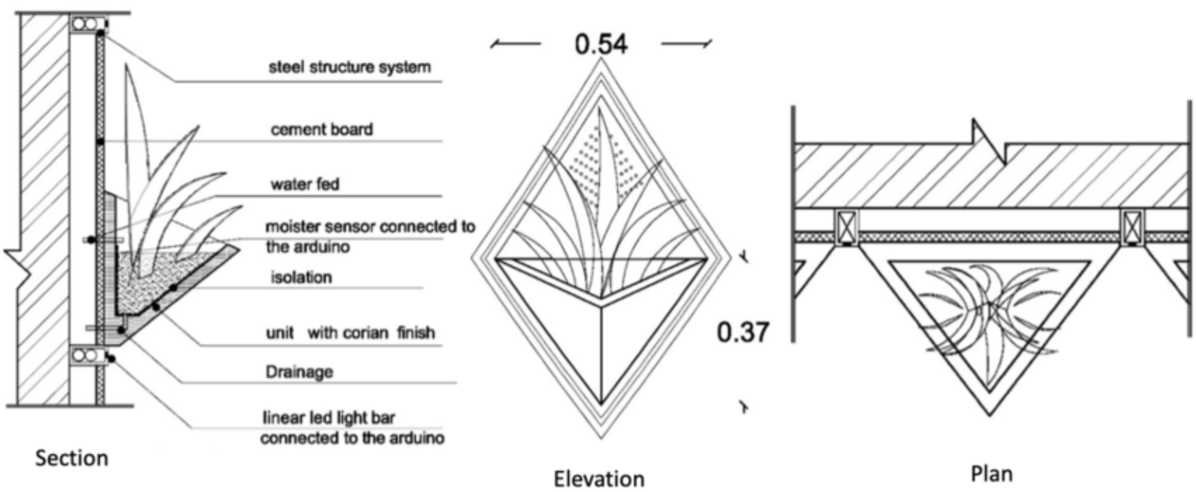

Fig. 8. Living wall details illustrating the components of the system

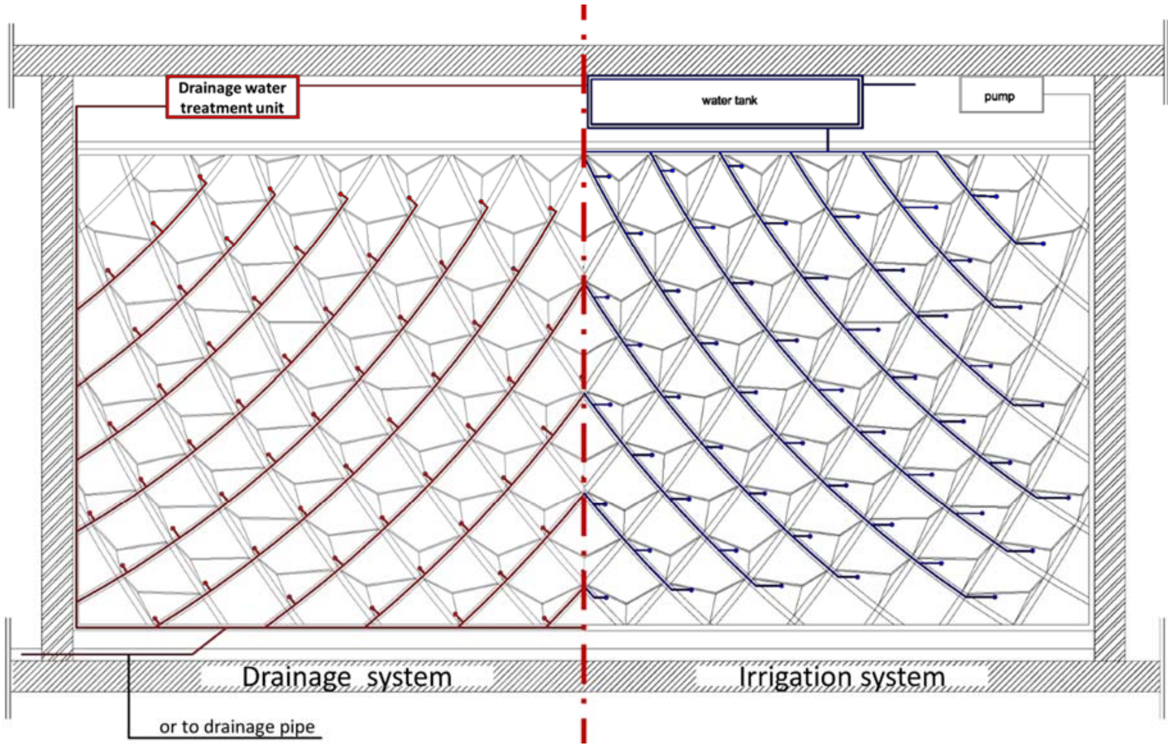

Fig. 9. Water management system for the pilot

concentration and productivity, alongside reduced stress levels and improved mood. This characteristic makes them well-suited for use not only in residential settings but also in commercial environments. Colors have the capacity to modify an individual's emotional state, transitioning it from a state of unhappiness or passivity to one characterized by cheerfulness or vitality.

Based on existing research on the impact of color on human emotions, a variety of hues were carefully selected with the aim of enhancing individuals' moods and subsequently increasing productivity in the workplace. For example, the yellow color was specifically chosen to evoke feelings of happiness, while the blue color was deliberately chosen to cultivate a sense of tranquility (Fig. 11). The regulation of these various colors is achieved by detecting sound levels generated by individuals within an indoor environment, in accordance with

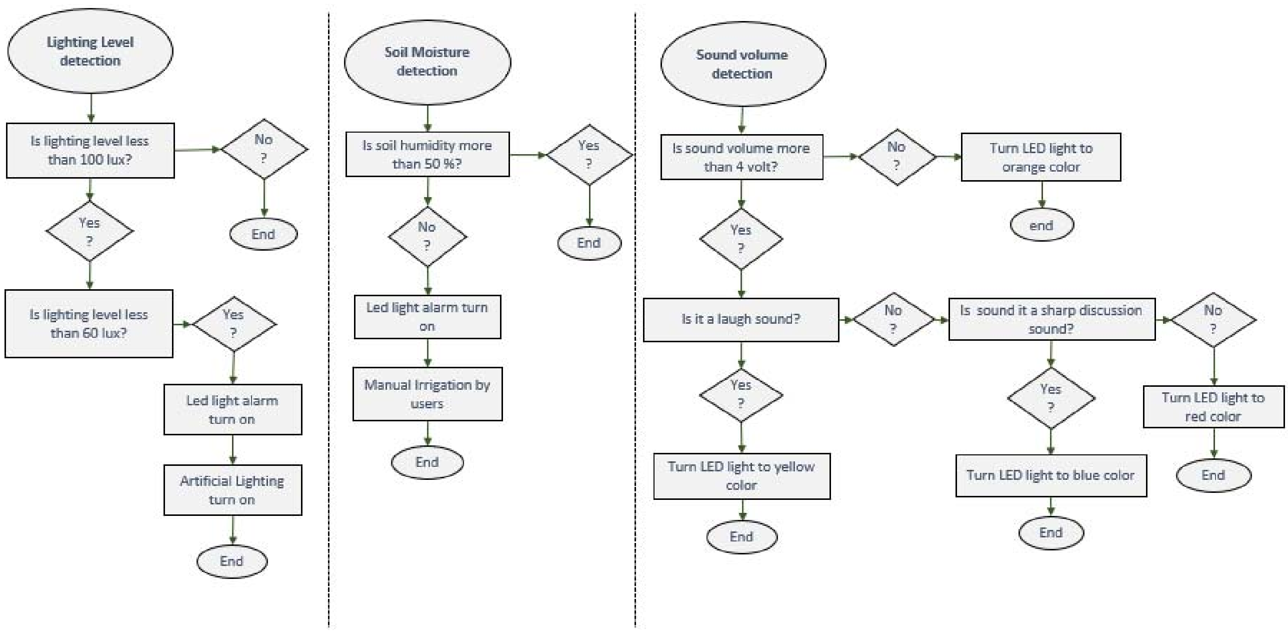

Fig. 10. Three different interactive status workflows for the three sensors in use

established guidelines for sound levels in such areas. The detection process involves identifying specific characteristics of sounds, including laughter, anger, and low conversational volumes.

Sound is quantified using the unit of measurement known as decibels (dB). A whisper typically registers at approximately 30 decibels (dB), whereas regular conversation often ranges around 60 dB. Prolonged exposure to noise levels exceeding 70 dB may potentially result in auditory impairment. Exposure to sound levels over 120 dB might result in rapid auditory damage.

The sound sensor module is equipped with both analog and digital output capabilities. The device operates across a range of supply voltages spanning from 3.3 to 5.3 V. This technology enables the detection of sound volume and the identification of distinct sound sources, facilitating the differentiation of the origin of the sound.

B. Soil moisture sensor

A new interactive approach has been implemented to determine the water requirements of plants. This form of interactivity pertains to the mutual relationship and interactions between humans and plants. The soil moisture sensor is used to measure the moisture content in the soil, providing an indication of the soil humidity level. This information is valuable for determining whether the soil is experiencing drought conditions and requires irrigation. The concept revolves around examining the threshold of drought tolerance in the chosen plants, beyond which they are unable to sustain themselves. At this critical point, an illumination system will be activated to indicate the need for watering the plant (Rivas-Sánchez et al., 2019).

The resistive soil moisture sensor measures soil moisture levels by evaluating the relationship between water content and electrical resistance. The sensors are equipped with a pair of probes that are fully inserted into the soil sample. There are two measurement scenarios based on the given information. In cases where the soil has high water content, there is a corresponding increase in its electrical conductivity. This increase in conductivity leads to a decrease in resistance levels, which serves as an indicator of elevated soil moisture levels. A decrease in the water content of soil leads to a reduction in its electrical conductivity, causing an increase in resistance, which serves as an indicator of low soil moisture.

C. Light sensors

The light sensor, commonly referred to as a photoelectric device, is capable of converting visible or infrared light energy, in the form of photons, into an electrical signal composed of electrons. Light sensors are commonly known as “photocensors” because they convert light energy, specifically photons, into electrical energy, specifically electrons (Rivas-Sánchez et al., 2019).

The green wall serves a primary function as a source of illumination due to two distinct factors. Primarily, it functions as the main source of ambient illumination for the occupants of the location. The ambient light of the green wall is activated in response to low levels of surrounding lighting. This light source serves to provide the plants with indirect illumination, which is crucial for their survival. In contrast to the sound sensor output, the response of this sensor is binary, activating when the ambient light level falls below a predetermined threshold based on the effectiveness of the lighting system, and deactivating when the room is adequately illuminated.

Fabrication and implementation

Three-dimensional printing stands as a notable example of additive manufacturing technologies that have had a substantial influence on the industrial sector. When it comes to developing prototypes for innovative concepts, it is widely acknowledged that 3D printing surpasses traditional methods by a significant margin. By utilizing virtual 3D models generated on a computer, it is possible to quickly fabricate three-dimensional objects using this approach. Throughout the duration of our pilot project, the green cell was fabricated into multiple components, which were subsequently joined together using adhesive materials before their installation on a steel framework system (Fig. 12).

The Arduino platform is an open-source system that includes user-friendly software and hardware components. The primary objective of this tool is to streamline the development process for diverse interactive projects across various scopes. Arduino is capable of perceiving its environment by receiving data from a diverse range of sensors. Additionally, it has the ability to exert an impact on its surroundings by manipulating various actuators, such as motors and lights, among others.

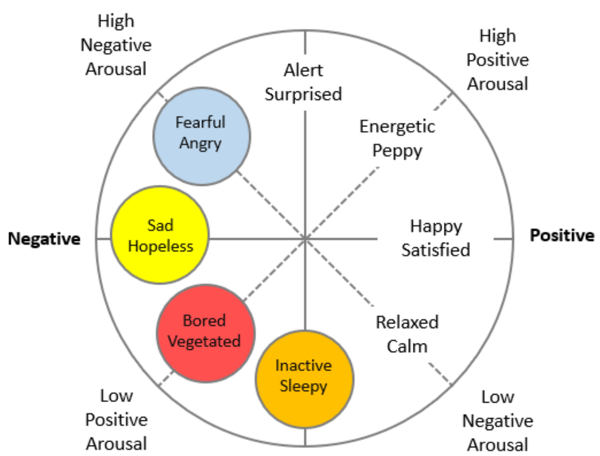

Fig. 11. Different color moods in response to negative or positive emotions

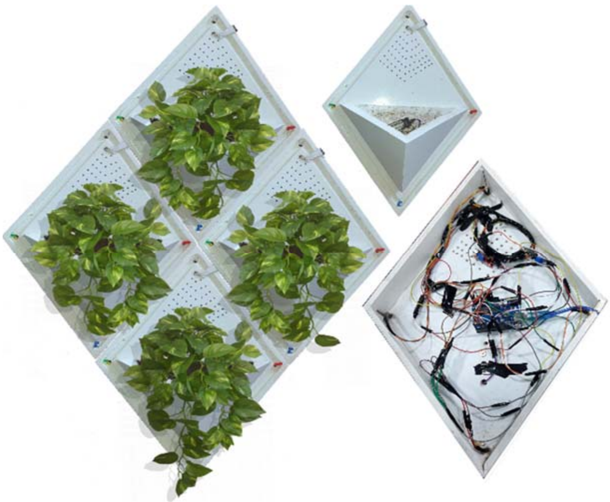

Fig. 12. Fabricated cell and its components

Arduino (Uno R3) was used in the pilot study to process data collected from three separate sensors and control the operation of the lighting system in order to display different color moods.

The completed design of the interactive green wall, along with its various components, is depicted in Fig. 13.

Conclusion

The purpose of this study is to improve the efficiency of the working atmosphere through the implementation of interior living walls. The present study involves developing a proposal and product for the design of a living wall that incorporates the principles of biophilic design. This endeavor is undertaken through the use of parametric analogical design and interactivity as key design approaches.

The product effectively incorporates five distinct biophilic design patterns within the categories of “nature in space” and “natural analogs”. The discussed patterns encompass both visual and non-visual connections with nature, as well as dynamic and diffuse light, biomorphic forms and patterns, and complexity and order, as outlined in Table 3.

The adoption of this technique will not only enhance the performance efficiency of architectural spaces, but it will also imbue the components of interior design with a renewed purpose as a direct result of this transformation. Consequently, the green wall will engage individuals using the indoor space, helping them improve their effectiveness as participants in the activities conducted in that area.

Acknowledgments

This research is based on a pilot study that was completed as a primary requirement of a postgraduate course titled “ARC616 - Interactive and Responsive Architecture” in spring 2020. We are thankful to our postgraduate students (Ahmed Amin, Hamis Montaser, Hend Ehab, Mai Hassan, Mohamed Emad, Nada El-Moghazy, Shehab-Eldin Mohamed) who contributed greatly to the research efforts.

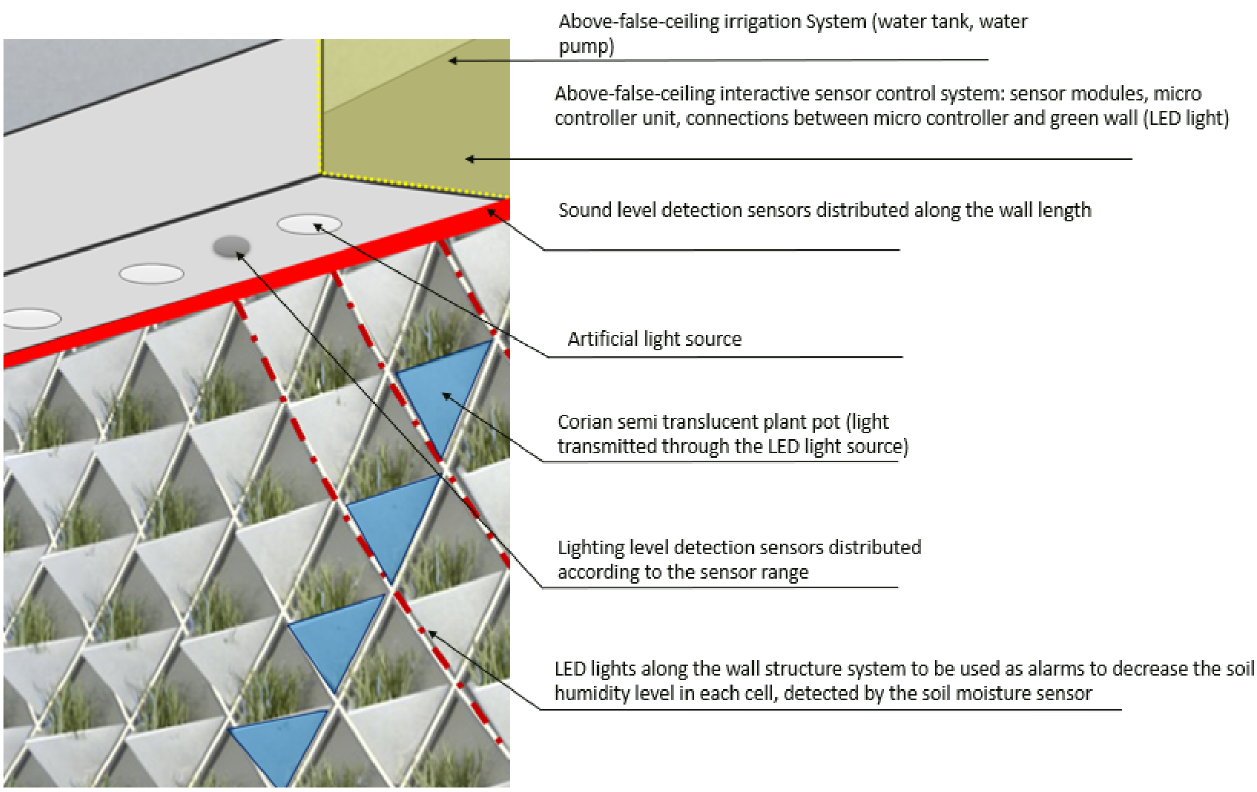

Fig. 13. Final design of the pilot and the Arduino controller

Table 3. **Five biophilic design patterns utilized in the construction of the product**

	Patterns	Application
Nature in Space	Visual connection with nature	Living wall in interior design
	Non-visual connection with nature	Living wall in interior design Interactivity systems
	Dynamic and diffuse light	Interactivity systems
Natural Analogs	Biomorphic forms and patterns	Parametric analogical design
	Complexity and order	Living wall in interior design Technical installation considerations

References

Almusaed, A. (2011). Introduction on growing media (soil). In: *Biophilic and Bioclimatic Architecture*. London: Springer, pp. 85–94. DOI: 10.1007/978-1-84996-534-7_6.

Assimakopoulos, M. N., de Masi, R. F., de Rossi, F., Papadaki, D., and Ruggiero, S. (2020). Green wall design approach towards energy performance and indoor comfort improvement: a case study in Athens. *Sustainability*, Vol. 12, Issue 9, 3772. DOI: 10.3390/SU12093772.

Briscoe, D. (2014). Parametric planting: green wall system research + design using BIM. In: *ACADIA 2014 - Design Agency: Proceedings of the 34th Annual Conference of the Association for Computer Aided Design in Architecture*, October 23–25, 2014, Los Angeles, USA, pp. 333–338. DOI: 10.52842/CONF.ACADIA.2014.333.

Browning, B. and Cooper, C. (2015). *Human spaces: the global impact of biophilic design in the workplace*. [online] Available at: https://greenplantsforgreenbuildings.org/wp-content/uploads/2015/08/Human-Spaces-Report-Biophilic-Global_Impact_Biophilic_Design.pdf [Date accessed July 7, 2022].

Dede, G., Pekarchuk, O., Özer, H., and Dede, O. H. (2019). Alternative growing media components for green wall designs in terms of lightweight. In: *2nd International Congress on Engineering and Architecture*, April 22–24, 2019, Marmaris, Turkey, pp, 374–383.

Downton, P., Jones, D., Zeunert, J., and Roös, P. (2017). Biophilic design applications: putting theory and patterns into built environment practice. In: *The International Conference on Design and Technology*, December 5–8, 2016, Geelong, Australia, pp. 59–65. DOI: 10.18502/KEG.V2I2.596.

Espiritu, K. (2022). *Peat moss: using sphagnum peat in the garden - epic gardening*. [online] Available at: https://www.epicgardening.com/peat-moss/ [Date accessed August 4, 2022].

Gunawardena, K. and Steemers, K. (2019). Living walls in indoor environments. *Building and Environment*, Vol. 148, pp. 478–487. DOI: 10.1016/J.BUILDENV.2018.11.014.

Johnstone, G. (2022). *Lipstick plant: care & growing guide: a cascading and constantly flowering houseplant*. [online] Available at: https://www.thespruce.com/lipstick-plant-care-5083734 [Date accessed August 4, 2022].

Kaumoodi (2021). Role of analogy in architecture design education. *International Journal of Engineering Research & Technology*, Vol. 10, Issue 9, pp. 164–172.

Kim, H., Huang, J., and Lee, J.-K. (2016). *A case study: projecting images for designing interior panels using parametric modeling tool. In: 2016 Proceedings of the 33rd ISARC, July*, 18–21, 2016, Auburn, USA, pp. 818–825. DOI: 10.22260/ISARC2016/0099.

Lundegren, M. (2016). *Green walls vs. green facades*. [online] Available at: https://archanatura.com/2016/02/01/green-walls-versus-green-facades/ [Date accessed February 2, 2016].

Madani, F., Mishra, A., Ibarra, M., Mansour, M., and Durairajan, S. (2013). *New product planning: case of indoor water plant system*. [online] Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3023593 [Date accessed July 9, 2022]. DOI: 10.2139/SSRN.3023593.

Meshram, A. and Srivastava, N. (2015). *Epipremnum aureum* (Jade pothos): a multipurpose plant with its medicinal and pharmacological properties. *Journal of Critical Reviews*, Vol. 2, Issue 2, pp. 21–25. DOI: 10.31838/jcr.02.01.04.

Nabil, S. and Kirk, D. (2019). Interactive interior design and personal data. In: Schnädelbach, H. and Kirk, D. (eds.). *People, Personal Data and the Built Environment. Springer Series in Adaptive Environments*. Cham: Springer, pp. 103–122. DOI: 10.1007/978-3-319-70875-1_5.

Peters, T. and D'Penna, K. (2020). Biophilic design for restorative university learning environments: a critical review of literature and design recommendations. *Sustainability*, Vol. 12, Issue 17, 7064. DOI: 10.3390/SU12177064.

Radić, M., Dodig, M. B., and Auer, T. (2019). Green facades and living walls—a review establishing the classification of construction types and mapping the benefits. *Sustainability*, Vol. 11, Issue 17, 4579. DOI: 10.3390/SU11174579.

Rakhshandehroo, M., Mohd Yusof, M. J., and Arabi, R. (2015). Living wall (vertical greening): benefits and threats. *Applied Mechanics and Materials*, Vol. 747, pp. 16–19. DOI: 10.4028/WWW.SCIENTIFIC.NET/AMM.747.16.

Rivas-Sánchez, Y. A., Moreno-Pérez, M. F., and Roldán-Cañas, J. (2019). Environment control with low-cost microcontrollers and microprocessors: Application for green walls. *Sustainability*, Vol. 11, Issue 3, 782. DOI: 10.3390/SU11030782.

Sarkar, A. N. (2018). Selection of plants for vertical gardening and green roof farming. *International Research Journal of Plant and Crop Sciences*, Vol. 4, No. 3, pp. 132–153.

Sheweka, S. and Magdy, N. (2011). The living walls as an approach for a healthy urban environment. *Energy Procedia*, Vol. 6, pp. 592–599. DOI: 10.1016/J.EGYPRO.2011.05.068.

Tamási, A. and Dobszay, G. (2015). Requirements for designing living wall systems – analysing system studies on Hungarian projects. *Periodica Polytechnica Architecture*, Vol. 46, No. 2, pp. 78–87. DOI: 10.3311/PPar.8337.

Wikimedia Commons (2022). *File:Money Plant (Epipremnum aureum 'N' Joy').jpg*. [online] Available at: https://commons.wikimedia.org/wiki/File:Money_Plant_(Epipremnum_aureum_%27N%27_Joy%27).jpg [Date accessed October 24, 2022].

Wilkinson, S., Carmichael, M., and Khonasty, R. (2021). Towards smart green wall maintenance and Wallbot technology. *Property Management*, Vol. 39, Issue 4, pp. 466–478. DOI: 10.1108/PM-09-2020-0062.

БИОФИЛИЯ НА РАБОЧЕМ МЕСТЕ: ПИЛОТНЫЙ ПРОЕКТ ПО СОЗДАНИЮ ФИТОСТЕНЫ С ИСПОЛЬЗОВАНИЕМ ИНТЕРАКТИВНОГО ПАРАМЕТРИЧЕСКОГО ПРОЕКТИРОВАНИЯ

Айман Ассем*, Доаа К. Хассан

Кафедра архитектурного проектирования, Инженерный факультет Университет Айн-Шамс, Египет

*E-mail: ayman.assem@eng.asu.edu.eg

Аннотация
Введение: Результат работы определяется не только производительностью труда и прибылью. Сам процесс и практические аспекты, сопутствующие достижению целей, также имеют большое значение. Между работодателями и работниками ведется непрекращающаяся дискуссия относительно концепции того, каким должно быть рабочее место. Основное внимание уделяется формированию всеобъемлющего подхода к труду и той среде, в рамках которой выполняется работа. Это исследование рассматривает связь с миром природы, в частности то, каким образом растения могут улучшить эстетику и поддержать хорошее самочувствие. Рассматривается реализация биофильного дизайна для борьбы с синдромом «больного здания» путем интеграции живой стены в интерьер рабочего места. **Методы:** В исследовании используется параметрический подход к проектированию для определения дизайнерского решения по включению живой стены в рабочее место. Этот подход повышает корреляцию между несколькими параметрами, влияющими на результат проектирования. Данный подход действует на двух уровнях. Во-первых, для определения формы элементов фитостены и формирования различных вариантов на основе параметров генерирования, полученных из природных источников, используется аналоговое проектирование. Во-вторых, в целях улучшения восприятия фитостены и ее различных вариантов применяется интерактивность, что в конечном итоге приводит к созданию уникальной атмосферы, которая подходит для самых разных видов деятельности **Результаты:** Подробно описаны результаты использования параметрического проектирования, включая успешное создание различных вариантов и форм элементов зеленой стены и улучшение восприятия сотрудниками при помощи интерактивности. Представлена эффективность этих дизайнерских решений в создании уникальной атмосферы и оптимизации взаимодействия сотрудников на рабочем месте.

Ключевые слова: биофилия, параметрический дизайн, фитостена, интерактивный дизайн.