Delta University Scientific Journal
Journal home page: https://dusj.journals.ekb.eg

Design indicators for the sustainable green transformation of the skin facades existing buildings. Case study: Delta University - Faculty of Engineering and Administration Building

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ABSTRACT

Existing buildings have significant negative impacts on the environment as they consume large amounts of energy and various resources. In September 2015, all countries around the world agreed to adopt 17 sustainable development goals. Egypt affirmed its commitment to achieve these goals by 2030. There has been a global shift towards a sustainable green transformation of buildings. Such buildings have been built using eco-friendly methods to use energy and resources more efficiently.

The research problem arises from the inability of the existing facilities in Egypt to do their role in achieving the concepts of sustainability and green transformation. These buildings cannot make the most benefit from the surrounding environmental potential in achieving the desired sustainability, increasing the health and productivity of the building's occupants, and promoting the building's consumption of the least amount of energy.

The research aims to achieve the concepts of sustainability in the existing buildings in Egypt by improving the thermal behavior using natural methods that act as an insulator and play an effective role in improving the psychological and aesthetic effect of the building.

The research methodology focuses on applying a theoretical study that deduces indicators for the design of the skin facades of the existing buildings using natural methods in harmony with the surrounding environment due to its environmental, psychological and spiritual impact on the occupants. The research is separated into two theoretical parts. The first part describes the role of nature and its psychological, spiritual, and mental effects on the inhabitants. The second part examines the role of nature as an influencer that helps to lower the thermal loads on the building envelope. The results of this study are a set of design indicators for the facades of the existing buildings to enhance the thermal behavior of the building skin through natural methods. The study presents one of the green transformation solutions for the skin facades of the Faculty of Engineering and the administrative building on the campus of Delta University for Science and Technology to achieve a sustainable green transformation in one of the existing buildings.

Keywords: *Existing building, natural methods, environmental impact, psychological, spiritual and mental impact, a sustainable green transformation.*

1. Introduction

The design of future buildings must be shaped by a different design language, starting from the pressures of sustainability to the evolving preferences of consumers. The need for developing energy-efficient and environmentally friendly buildings has given rise to the principles of green design, which involve applying renewable energy systems, using materials, reusing materials, and integrating nature into architectural elements. This, in turn, helps create a harmonious blend of nature and man-made structures.

Hence, design techniques tend to achieve uniqueness and personality, leading to more creative and experimental designs. In fact, future aesthetics are not only about visual appeal, but also about enhancing the user experience, promoting well-being, and creating a sustainable future.

Natural aesthetics evoke a sense of comfort away from the concrete jungles of urban concrete. Many studies indicate that exposure to green spaces has a relaxing psychological effect, as it reduces stress, lowers blood pressure, and stabilizes the heart rate. This natural touch enhances the general well-being of the residents and adds great value to the residential and commercial properties (Akshat chadha, 2022).

The facades of buildings are technically considered as one of the most complex aspects of architecture. They act as barriers between the interior areas of buildings and the surrounding environment, i.e. the filter layer between the outside and the inside. In buildings, the internal environment must be maintained within certain limits to provide comfort to the residents. The external environment is variable as it changes significantly throughout the year. The main factors that must be taken into consideration include sunlight, temperature changes, rainfall fluctuations, air humidity, and wind effect. To conserve energy, it is necessary to achieve optimum use of energy from the inside and outside of the facade while maintaining a healthy and enjoyable internal climate.

The second role of facades is to be aesthetically pleasing and appealing and to improve well-being. These facades affect human awareness and individual emotions which differ from one individual to another. Aesthetics are linked to the characteristics of facades including prestige and symbolism. Building facades reflect the civil and cultural identity and aims to convey strength and significance (Sandak, 2019). The research does not address the basic principles of aesthetic evaluation of existing buildings. Instead, it focuses on the significance of achieving aesthetics and environmental protection for the facades of these buildings using natural ways to make these buildings unique and distinctive.

In the Arab Republic of Egypt, there is a dire need to make a conscious choice to transform the existing buildings into a more proactive style that uses natural methods to reduce the consumption of non-renewable energy, lessen pollution, minimize energy costs, and improve the climate. Therefore, it is necessary to rely on methods that are more comfortable, healthy, and safe for users and occupants of the places where they live and work. In the twenty-first century, the necessity of green architecture began to be realized. In addition, new aspects began to appear, which helps to stress the importance of developing these procedures that can mitigate global warming and climate change at the urban and local levels.

This research seeks to analyze the benefits of treating the building envelope in natural ways and study the basic concepts and advanced aesthetic and environmental theories. It aims to implement projects and apply the behavior of the green envelope on the outdoor spaces of an existing building. The research is conducted in 3 parts:

The first part: A theoretical part that discusses the role of nature as an aesthetic factor, where the importance of nature in improving the behavior and comfort of users is studied.

The second part: A theoretical part that discusses the role of nature as an environmental factor, studying the different ways of using nature as a building envelope and as a method to mitigate the environmental impact and achieve external and internal comfort.

The third part: A practical part where natural methods are applied to the envelope of the existing administration building at Delta University for Science and Technology.

2. The role of nature as an aesthetic influence on the building skin

Sustainable architectural ethics cannot be deemed complete unless they include the issue of aesthetics. However, the connection between beauty in nature and architecture must be clearly defined. The beauty of the natural world can be manifested in the natural process. Additionally, the beauty of the architectural world must be taken as part of the natural environment. Therefore, by using natural elements as models of sustainability, an expression of sustainable aesthetics can be achieved.

2.1. Aesthetics and the natural environment

Aesthetics is a branch of philosophy that deals with the nature of art, beauty, and taste, with the creation and appreciation of beauty in mind. It is a pleasurable engagement that gives meaning to life. This experience is a contemplation that helps to perceive the environment correctly.

Before the 19th century, Western aesthetics usually referred to the Greek philosophers as the earliest source of formal aesthetic considerations. Plato believed in beauty as a "form" in which beautiful things participate and cause them to be beautiful. He felt that beautiful things involve proportion, harmony, and unity among their parts. Since the 19th century, with advances in psychology, new concepts in aesthetics have emerged. The idea of beauty has shifted to more subjective concepts where beauty is believed to be related to human perception. Since psychological and social factors influence human perception, they are also capable of shaping one's ideas about beauty. Thus, it is generally believed that beauty is not just a visual matter, but a quality or set of qualities that give intense pleasure to other senses or enchant intellectual or moral faculties.

As much as the artfully designed landscapes express their own beauty, Spirn adds, “This beauty involves a dynamic process of movement and change, rather than static objects”. In other words, it refers to what is represented as aesthetics of sustainability that is more than pictorial landscapes and idealized pastoral scenes, but rather involves sensory, bodily experiences of places that lead to new awareness of the rhythms and cycles necessary for sustaining and renewing life (Hemmati, 2017).

The term aesthetics refers to sensory perception, understanding, or cognitive knowledge. In the 18th century, Baumgarten changed its meaning to sensory satisfaction or sensory pleasure. Why beautiful things are considered beautiful is still a mystery. Aesthetic judgment, aesthetic attitude, aesthetic understanding, aesthetic emotion, and aesthetic value can be used to help explain the aesthetic experience. Such aesthetic experience profoundly affects our lives and influences our decisions about important behaviors. These experiences include sensory perception, captured perception, cognitive, and emotional responses. Visual aesthetics influence consumer perception in several ways. Additionally, visual aesthetics have a symbolic function that influences the way products are perceived and evaluated. Rokka and Uusitalo found that more environmentally friendly objects have a positive effect on consumer attitudes or preferences. In the context of architecture, the same is held as true. Thus, it can be concluded that aesthetics will be influenced by perceived or tangible nature along with sustainability (Zhang Y. S., 2023).

2.2. Environmental stress

Since the early sixties, it was found that environmental psychology overlaps between architecture and psychology, as environmental conditions directly affect the causes of stress reactions and pressure on emotions such as anxiety, fear, anger, etc., where emotions affect every aspect of performance, morale, and physical health. Therefore, great attention must be paid to the environment. Not only environmental conditions directly affect the causes of stress reactions, but also environmental settings. Many of those who call themselves environmental psychologists tend to focus on the physical environment because of its major role in reducing stress as well as enhancing motivation and response (Altman I, 1977). Thus, environmental stress is the emotional, cognitive, and behavioural responses as an environmental stimulus (or stressor). Bilotta and Evans (2013) defined environmental stress as an imbalance between environmental requirements and human response capabilities (Fleury-Bahi, 2017).

2.3. Biophilia: an innate love of nature

Biophilia is the innate human tendency to belong to nature (Kellert S. C., 2015). It is the first term that the psychoanalyst Foreman coined for life in his exploration of *The Essence of Man* and it was defined as a love of life and living processes (Söderlund Jana, 2015). Human communication with nature is a requirement that makes one happier with the feeling of beauty, entertainment or change. Besides, it has a fundamental role in health and improvement as it is a need for presence and a deep intrinsic desire that makes it a source of life and generates a human society characterized by health and productivity. It helps in making buildings and cities more effective and humane (Makram, 2019). For the successful application of biophilic design effectively, there are some basic principles which are explained in Figure 1.

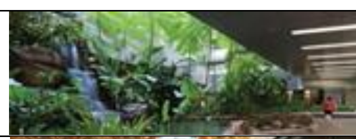
Principles of Biophilic Design		**1.** Continuous and frequent participation with nature.
		**٢.** Focus on the adaptation of man with nature to enjoy health, fitness and well-being.
		**3.** Encourage emotional attachment to places and surroundings.
		**4.** Establish positive interactions between people and nature, which generates connection between human and natural societies.
		**5.** Encourage support for alternatives to interrelated and integrated architectural solutions.

Figure 1: Principles of biophilic design (Kellert S. C., 2015)

The features of biophilic design are divided into 3 different categories. Table (1) illustrates the relationship between humans and nature and uses 14 patterns as a tool to improve well-being in the built environment (Söderlund Jana, 2015).

Table 1: Patterns of biophilic design (Söderlund Jana, 2015), (Ryan CO, 2014)

Nature in the space	 Integration of plants, water, and animals into the built environment, particularly with motion	1. Visual association with nature: green roofs, and living walls, plants inside and out, water, nature artworks. 2. Non-visual association with nature: weather, sun patches,textured materials , nature odors, bird sounds. 3. Non-rhythmic fantastic motive: nature sounds, water,clouds, shadows, ,nature reflections. 4 Thermal and airflow variability :shade, radiant heat, seasonal vegetation. 5. Presence of Water: rivers, fountains, water walls, ponds, daylighted streams (To be able to see, hear or touch it). 6. Dynamic and diffuse light—light from vrious angles, ambient diffuse lighting, circadian lighting. 7. Link with natural systems—seasonal patterning, wildlife habitats, diurnal patterns.
Natural analogues	 One step away from real nature; patterns and materials that induce nature	8. Biomorphic forms and patterns—organic building forms, structural systems (savannah effect). 9. Material association with nature—organic building forms, structural systems (savannah effect). 10. Complication and order—fractal patterns, sky lines, plant selection, and variety, material textures, and colors.
Nature of the space	 Psychological and physiological human response to varoius spatial configurations	11. Prospect :views, balconies, 6 m and above focal lengths, open floor plans. 12. Refuge :protected spaces, overhead canopies or lowered ceilings, places furnishing concealment. 13. Mystery—winding paths, masked features, flowing forms. 14. Risk/peril—floor to ceiling windows, water walks, high walkways.

Nature also reflects three health responses on humans: cognitive, psychological and physiological Table (2). Therefore, the design of biophilia is important to the designer and planner (Ryan CO, 2014). The design of biophilia is not the presence of greenery in our buildings or increasing their beauty by introducing trees or shrubs. It is much more than that. It is the construction of a human place generated from nature, and thus the generation of a natural global place that generates a human society (Salingaros, 2015).

Table 2: Biophilic design categories & biological responses (Ryan CO, 2014)

<table>
<tr><th>Biophilic Design</th><th>Nature in the space</th><th>Natural analogues</th><th>Nature of the space</th></tr>
<tr><td>Biological responses</td><td rowspan="2">− Lowered blood pressure and heart rate.
− Reduced systolic blood pressure and stress hormones.
− Positively impacted on heart rate, systolic blood pressure and sympathetic nervous system activity.
− Positively impacted comfort,well-being and productivity.
− Reduced stress, increased feelings of tranquility, lower heart rate and blood pressure.
− Positively impacted circadian ystem functioning.
− Increased visual comfort.</td><td rowspan="2">− Positively impacted perceptual and
− Physiological stress responses.</td><td rowspan="2">− Reduced stress.</td></tr>
<tr><td>Stress reduction</td></tr>
</table>

Cognitive performance	− Improved mental engagement/ attentiveness. − Positively impacted on cognitive performance. − Observed and quantified behavioral measures of attention and exploration. − Positively impacted concentration. − Improved concentration and memory restoration. − Enhanced perception and psychological responsiveness.	− Decreased diastolic blood pressure. − Improved creative performance.	− Reduced boredom, irritation, fatigue. − Improved concentration, attention and perception of safety.
Emotion, mood & preference	− Positively impacted attitude and overall happiness. − Perceived improvements in mental health and tranquility. − Improved perception of temporal and spatial pleasure. − Observed preferences and positive emotional responses. − Enhanced positive health responses; shifted perception of environment.	− Improved comfort. − Observed view preference.	− Improved comfort and perceived safety. − Induced strong pleasure response. − Resulted in strong dopamine or pleasure responses.

3. The role of nature as an environmental influence on the building skin

Modern construction and engineering achievements have demonstrated a global civilization where design and the built environment over-exploit technology and separate people from natural or living systems. The result is an urban world characterized by unsustainable consumption of energy and materials, widespread air and water pollution, climate change, waste generation, and unhealthy indoor and outdoor environments. To improve the ecological balance of cities and reduce the major negative effects of urbanization, existing building envelopes and context must be addressed to adapt to a green living system as an effective solution that achieves comfort at the building and the urban levels.

3.1. Nature environmental advantages

- **Heat island effect mitigation**

The term urban heat island refers to the effect that causes air temperatures near the surface of cities to be higher than in nearby suburban or rural areas. The study of urban heat island effects is a major human modification of the urban environment (Živković, 2018). The use of vegetation in the built environment regulates the urban microclimate and improves the thermal behavior of the building envelope.

- **Indoor air quality**

Nature affects the factors of the indoor environment such as thermal comfort, daylight, natural air, indoor plants, good views and natural landscapes (Figure 2). All of these elements function to achieve a high-quality indoor environment besides its environmental advantage of energy-saving. Consequently, planting facades, shading, and green roofs achieve thermal, visual, and acoustic comfort (Söderlund Jana, 2015).

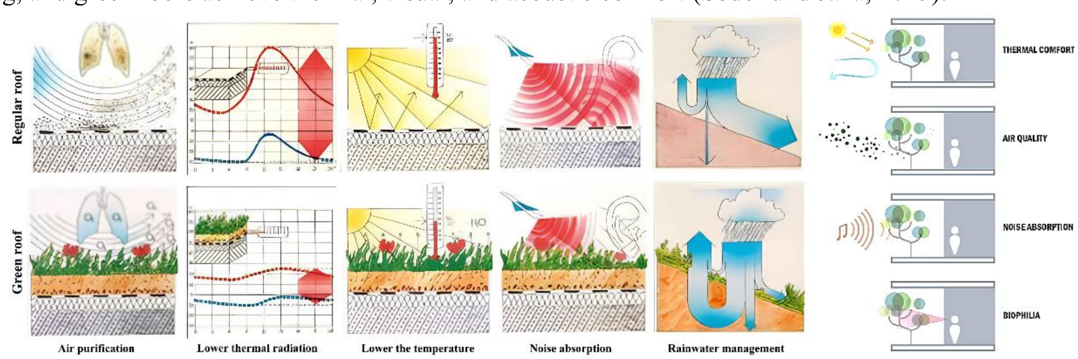


Figure 2 (a, b): Manifest greenery for the environmental issues (Green Roof Types, 2021) (Testado, 2024)

- **Air pollution removal and Carbon footprint reduction**

Plants remove pollutants directly and indirectly. They absorb gaseous pollutants through their stomata, intercept particles with their leaves, and are able to break down some organic compounds such as polyaromatic hydrocarbons in their plant tissues or in the soil. They contribute to improving air quality through their ability to capture particles on the rough surfaces of leaves as air passes over them. A 1,000-square-meter green roof can capture 160-220 kg of dust per year, reducing the dust concentration in the atmosphere by about 25% (Živković, 2018).

Green tree leaves help reduce carbon through plant metabolism sequestering carbon in the roots and stems. Thus, biophilic design initiatives in cities such as green roofs, living walls, and urban trees influence carbon reduction by reducing energy consumption associated with green roofs and insulating walls (Söderlund Jana, 2015). The ability of a green roof to fix carbon and release oxygen depends on the choice of plants. Trees, shrubs and bushes are better at controlling carbon dioxide concentration, improving the environment and maintaining oxygen balance than grass (Živković, 2018).

- **Conserving biodiversity**

Biodiversity on Earth is the variety of all life forms and biological processes. While green infrastructure provides ecosystem services and economic benefits, a biodiversity design is the basis for protecting and maintaining flora, fauna and habitat (Mike, 2011).With the increasing urbanization, the significance of conserving biodiversity in cities is growing. Hence, green roofs and walls with the selection of appropriate plant species have the potential to mitigate the loss of ecosystem services in urban areas. An example of creative green urban infrastructure is the New York High Line Park (Figure 3). The railroad has been developed and maintained by planting 300 species of perennials, shrubs, trees and wildflowers along the line that attract bees, butterflies, birds and other insects. It has had a tremendous impact on the neighborhoods it traverses, increasing property values, enhancing local identity, generating healthier community activity, improving public safety, reducing pollution, and enhancing biodiversity (Christina, 2015).

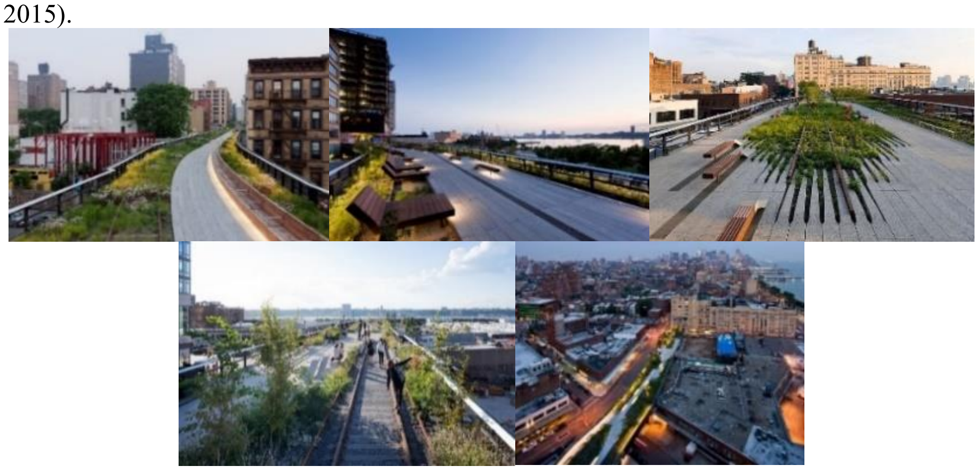


Figure 3: The green development of The New York High Line Park (Baan, 2009)

- **Sterilization**

Garden plants, as the main species in urban afforestation, play an important role in reducing the amount of pathogenic microorganisms, which are harmful to the environment, improving the ecological value of the urban environment, and adding social benefits. Plants can sterilize and inhibit bacteria and other pathogenic microorganisms in their living environment to varying degrees. The high green coverage rate helps reduce the bacteria content in the air. Some tree species produce essential oils called fungicides, which improve mental health when inhaled (Živković, 2018).

- **Water management**

Vegetative cover and green roofs can reduce rainwater runoff and retain 70% or more. Besides, pollution of waterways can be reduced by controlling rainwater runoff using green roofs to absorb the rainwater. The Living wall system acts as a bio-filter that efficiently purifies water through plant treatment during plant filtration and root filtration processes (Söderlund Jana, 2015).

3.2. Building envelope of natural skin façade

3.2.1. Green louvers

The utilization of vegetation promotes the shading performance towards influencing thermal and visual comfort (Kristanto, Canadarma, Oentoro, & Wayne, 2023). Hence, it contributes to raising the greenery percentage which reduces the exposed sunray areas and raises vertical greening shading efficiency (Sharbafian, Yeganeh, & Motie, 2024). Shaded facades reduce indoor temperatures and delay solar heat transfer, which helps reduce energy consumption for air conditioning (Söderlund Jana, 2015). In hot dry climates, the vertical greening system of the south façade for students' residential campus building in Jordan minimizes the south façade temperature by 5degrees Celsius compared to the essential phase (Freewan, Jaradat, & Amaireh, 2022). Using vegetation for shading devices enhances the building envelope's aesthetic which contributes to earning vertical greening systems' properties (Figure 4).

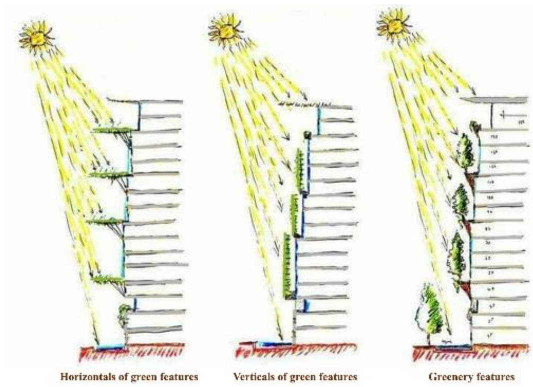


Figure 4: A greenery solar shading (Huidobro, Browne, Browne, & Huidobro, 2024)

3.2.2. Green screens

According to (Mahrous, Taha, & Abdel-Karim, 2023) various vertical green screens apply plants as sustainable materials for their passive properties of shading, evapotranspiration, thermal insulation, and wind barrier. Green coverage for walls is considered an environmentally friendly structure with the qualities of an air space and a climatic envelope layer that act as thermal and acoustic insulators and energy savers which reduces heating and cooling costs. Moreover, green walls for the interior and exterior provide shade, encourage breezes, act as air filters, and absorb sound. There are two types of green wall systems: extended and intensive green walls (Figure 5). Extended walls are divided into suspended green patches and integrated into suspended green wall systems. While intensive walls are divided into living walls and energetic biophilic walls (Aya, 2018), green facades have great opportunities to perform the environmental role of plants as they can double the footprint of the building with greening compared to green roofs (Al-Kayiem, Koh , Riyadi, & Effendy, 2020). Vegetated facades reduce the UHI effect by about 2 degrees Celsius, improve indoor air quality, achieve thermal comfort and human health, and save electricity consumption by 5-10% (Söderlund Jana, 2015) . Vertical greening systems of facades, walls, terraces, and vertical forests are essential methods to raise planting capacity by integrating green coverage with the built environment (Wang, Gard, Borska, Ursem , & van de Kuilen , 2020).

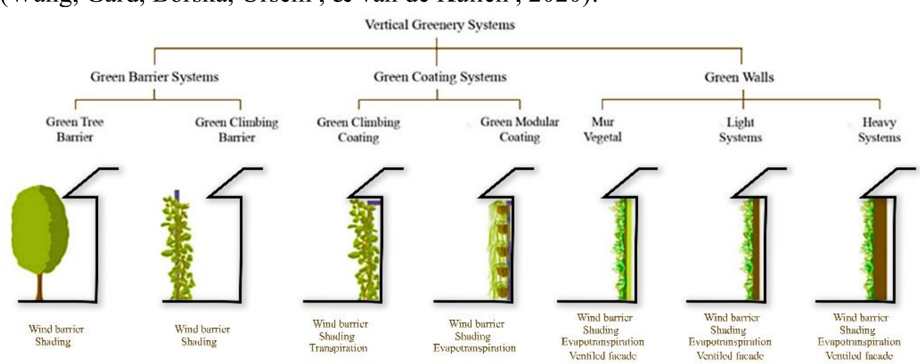


Figure 5: A classification of vertical greening with its environmental advantages (Arenghi, Perra , & Caffi , 2021)

3.2.3. Green roofs

At the urban level, green infrastructure of various green roof types achieves aesthetic, psychological and social benefits by enhancing well-being and mental and physical health (Mihalakakou, et al., 2023). Green roofs are horizontal or sloping surfaces partially or completely covered with plants (Figure 6). The greenery of the roof or sidewalk reduces 4 degrees Celsius from the original state and reduces noise levels by 8:10 DB (Abass, Ismail, Wahab, & Elgadi, 2020). Environmentally, green roofs contribute to solving many problems at the urban level to increase biodiversity, reduce the heat island effect, improve the energy efficiency of buildings, purify and reduce air pollution, convert carbon dioxide to oxygen (Jaffal, Ouldboukhitine, & Belarbi, 2012), filter, absorb, and retain rainwater. In addition, it has economic benefits that increase the roof lifespan, protect the roof membrane with high quality and reduce electricity use in summer by 5-15%. Besides, it helps in reducing energy consumption through cooling effects and insulation for hot climates and reducing heating loads for cold climates (Söderlund Jana, 2015).

Figure 6: Horizontal greening with green roofs (Green Roof Types, 2021)

3.2.4. Air envelopes

The design of an air-based building envelope contributes to higher building performance, as solar energy is a natural source that can be integrated into the air-based envelope system to achieve natural cooling and heating (Luo, et al., 2019). Building envelopes with an internal air layer classified according to (Zhang, Tan, Yang, & Zhang, 2016) as closed, naturally ventilated, and mechanically ventilated contributes to reducing the building's heat load, providing heating, and improving thermal comfort and indoor air quality. Therefore, It is more efficient to utilize double-skin wall systems with climbing plants on the supporting walls via the air layer between the wall and the green layer to reduce temperatures for the comfort of both the indoor and outdoor environment (Figure7).

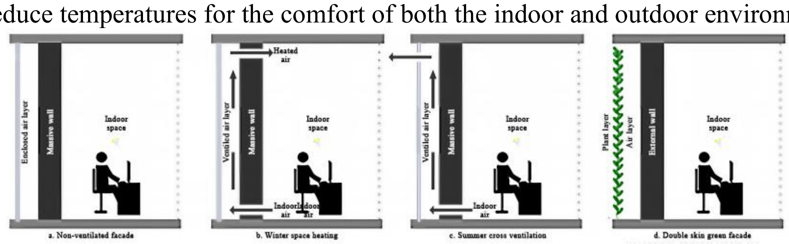


Figure 7: Air-based system (Zhang, Tan, Yang, & Zhang, 2016)

3.2.5. Water walls

The water wall system has a water layer sandwiched between two panels of opaque, semi-transparent, or phase-changing materials. The water wall system for facades is characterized by its humanistic benefits which ensure fire safety in addition to its economic benefits of reducing energy demand (Rathnayake, Lau, & Chow, 2020). Water-based exterior cladding operated by spraying or water pipes (Figure 8) has the potential to reduce cooling loads effectively, contribute to reducing heat flow through glass facades, and remove heat energy absorbed by the surrounding air and sunlight due to the circulation of running water (Luo, et al., 2019). Consequently, this system is an effective strategy that contributes environmentally to maintaining thermal comfort for occupants by transferring low heat to the interior. In its transparent state, it allows daylight to enter and reduces dependence on artificial lighting (Rathnayake, Lau, & Chow, 2020).

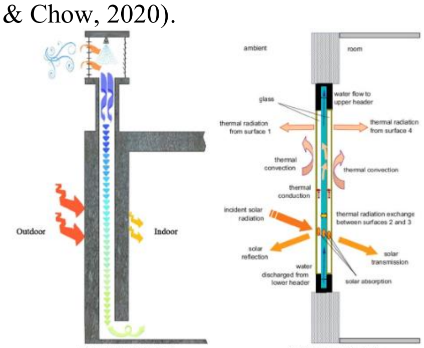


Figure 8: Schematics for water-based wall systems (Luo, et al., 2019)

3.2.6. Natural materials

- **Thermal insulators**

Thermal insulation is a material with high thermal resistance and low thermal conductivity. A previous review indicated that examples of nature-based insulation materials (Figure 9) include cork, wood wool, low-density fiberboard, wood panels, reeds, straw bales, flax, hemp, sheep wool, cellulose insulation, cotton, coconut fiber, and seaweed (Bozsaky, 2019). Thermal conductivity values of natural materials can vary significantly depending on the density, particle size, and type of binder used. In addition, utilizing natural fibers as aggregates can enhance the physical properties of existing commercial materials (Cosentino, Fernandes, & Mateus, 2023). When a comparison was made between a group of synthetic insulation materials and a natural insulation material, the result confirmed that cellulose fibers were the best solution to the adverse environmental impacts of material production. Recent technological developments can contribute to overcoming the known problems of natural insulation materials such as resistance to moisture, fire, and pests, in addition to developing innovations for bio-based materials (Bozsaky, 2019).

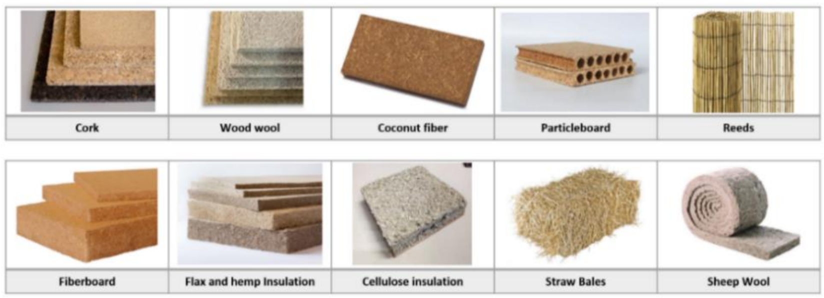


Figure 9: List of natural materials from vegetal and animal resources widely reviewed as thermal insulators. (Cork Sheets - DIY , 2023) (Wood Wool Board, 2022) (Fernandez, 2022) (Yachen (manufacturer), 2022) (Natural Reed Garden screen, n.d.) (Pavatex Wood Fibre Insulation, n.d.) (HEMP WOOL INSULATION BATT, n.d.) (BEST INSULATION-Cellulose Fibre, 2019) (Wheat Straw Bale, n.d.) (Thermafleece - Cosywool Sheeps Wool Insulation, n.d.)

- **Cool roofs and envelopes**

According to (Pisello & Rosso, 2015), the US Environmental Protection Agency (EPA) has confirmed the importance of cool roofs and pavements limiting the urban heat island for people's health and economic sustainability in cities. In the experiment of replacing concrete pavements with marble pavements, the average peak ambient temperature decreased by 1.2-2 degrees Kelvin. In addition, by cooling the building envelope in two regions in Jordan, the decrease in the level of thermal absorption (from 1 to 0) was able to reduce the energy load of uninsulated buildings by up to 32% in the temperate climate region, and by up to 47% in the hot climate region. Consequently, cool roofs and natural pavements (Figure 10) reduce the average temperature which is positively reflected in reducing the heat island effect.

Figure 10: Set of nature-based cooling materials for roofing and paving (Pisello & Rosso, 2015)

- **Biomaterials louvers**

While the use of external shading devices (Figure 11) is essential to reduce the cooling loads of buildings in hot climates (Kellert S. , 2018), bio-based building materials in the construction sector promote green architecture by reducing waste and enabling multi-use building designs that are appropriate to local contexts. The book Bio-based building skin describes the properties of several bio-based materials and gives examples of their use in cladding envelope and shading. In addition, it offers solutions that can be applied to existing buildings (Kirimtat, Koyunbaba, Chatzikonstantinou, & Sariyildiz, 2016).

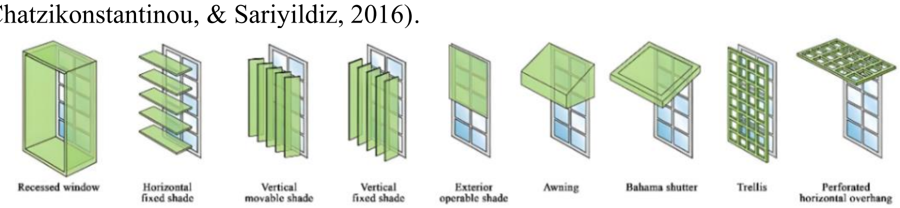


Figure 11: Types of shading devices for exterior openings (Al-Yasiri & Szabó, 2021)

3.2.7. Organic patterns and forms screen

According to (Bystrova, T Y, 2019), organic forms in architecture are forms that are similar to nature in their structure. Architecture has recently been linked to the natural environment through new technologies and materials. The study (Bystrova, T Y, 2020) presented three trends for designing organic forms: the form should be logical in its compatibility with the functional purpose, the form as a whole should be close to describing the elements of nature, or the whole form should be inspired to enhance the sensory aspects. An example of biodynamic Panels utilized for facade is Expo Pavilion 2015, Milan, Italy (Italy Pavilion Milan Expo 2015, 2015). As the study explained (Fauziah, Kurniawaty, & Bahar, 2020), organic architecture can be understood through seven features: the building draws its design from nature, the design process is in a state of continuous development, the form is in a dynamic state with the environmental and urban context, the creative and sensory connection of the building to meet the needs of the user easily, ensuring that the building is linked to the topography of the site with sound thinking, enhancing the use of local materials, and paying attention to adding an interesting youthful and childish touch as an individual character enhanced by organic architecture.

3.3. Building context of natural skin façade

3.3.1. Open space

Under LEED (LEEDuser, 2017), open space requires 30% or more of the total site area to be covered by open space, with at least 25% being natural vegetation or green canopy. This can include paving and grass areas that promote outdoor social activity, attractive year-round vegetable garden space, food garden space, and areas for conservation and restoration of native habitat. The research (NASSAR, 2021) concluded that planning the open spaces of the campus enhances the urban fabric of the city. However, it should be transformed from a car-oriented environment to a pedestrian-oriented environment. Thus, it should cater for diverse activities with varying spaces, diverse configurations, and consideration of the spiritual humanistic dimension.

3.3.2. Overhead canopy

Overhead canopy is a shading strategy that can improve indoor and outdoor environmental quality and reduce cooling loads (Al-Yasiri & Szabó, 2021). According to the required aesthetic or functional value, it acts as a shading device used in landscaping, building entrances, and near building facades. The planted canopy contributes to the 25% greenery in open spaces for LEED credit (LEEDuser, 2017).

3.3.3. Green shady

The placement and position of trees (Figure 12) act as a key to the idea of energy savings as they affect summer electricity use so that the amount of shade needed for the area could be determined. Tree shade reduces energy by cooling and transferring summer breezes to the desired locations where the amount of savings depends on the location and position of the trees. While specific types of trees provide shade for the building, the most popular shade trees are oaks, maples, ashes, lindens, elms and palms for hot locations (Aya, 2018). In general, shading trees in urban landscapes reduces 25% of the net energy use for cooling and heating in urban areas. The use of vegetation in the built environment regulates the urban microclimate and improves the thermal behavior of the building envelope. For example, 16 shading trees provide 30% of the cooling energy while shading with heat-absorbing vegetation on roofs can reduce daily temperature fluctuations by 50% and evaporation can divert large amounts of solar radiation (Söderlund Jana, 2015). A study analyzing how tree canopies affect wind flow concluded that the wind barrier near the tree is not significantly effective. Tree canopy thickness affects the wind speed between the trees. Hence, lower levels of tree canopy porosity lead to limited wind barrier performance (Jian , Bo, & Mingyue, 2018). Consequently, the location and position of the tree affect natural ventilation so its effect on the building envelope should be studied by considering the location of openings and air movement within the spaces.

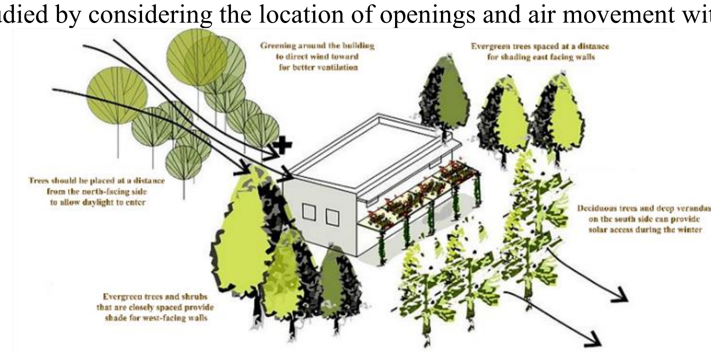


Figure 12: Solar shading with trees (Nisar, Ashraf, Parveen, & Islam, 2017)

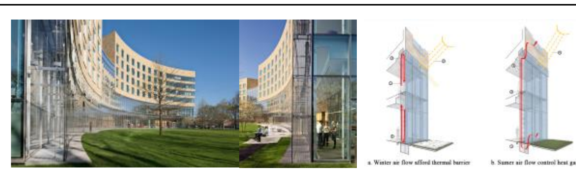
3.3.4. Nature-inspired solutions to the local context

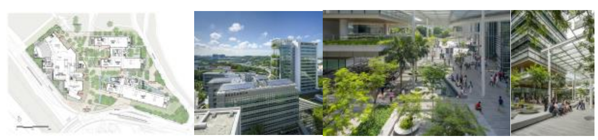
Biomimetic design is a recent approach in the field of bioinspiration that brings observed biological principles into the design. By engaging with multiple disciplines, biomimetic architectural movements foster creativity and innovation (Chayaamor & Heil, 2023). The biomimicry approach impacts environmental and urban sustainability by positively influencing the well-being of individuals and communities while maintaining the integrity of ecosystems (Blanco, Zari, Raskin, & Clergeau, 2021). For example, (Figure 23) shows a nature-inspired solution in light of the biological aspects that offer creative and innovative ways to address problems in the built environment. (Solano, 2023).

4. Design indicators of the skin façade existing building

The research concluded a set of design indicators for the aesthetic and environmental aspects of the envelope of existing buildings to adapt to a green living system as an effective and sustainable solution to improve the environmental balance of cities and to reduce the main negative effects of urbanization, which achieves better comfort at the building and urban levels. Table (4).

Table 4: The examples analysis for the deduced strategies

<table>
<tr><th colspan="2">Skin façade indicators</th><th>Environmental indicators</th><th>Examples</th><th>Aesthetics indicators (Biophilic features)</th></tr>
<tr><td rowspan="4">Building Envelope</td><td>Green louvers</td><td>The utilization of green features for existing exterior envelope to promote solar shading with greenery.
• Horizontal green shading device
• Vertical green shading device
• Vertical green terraces</td><td>
Figure 13: A vertical greening system of the green louvers for the Institute of Physics at Humboldt University in Germany (Gilsenbach, 2021)</td><td rowspan="4">Nature in the space</td></tr>
<tr><td>Green roofs</td><td>The retrofitting of vertical or sloped roofs of existing buildings with green features.
• Solar garden/green roof
• Blue green roofs/Blue roofs
• Extensive green roof
• Semi-intensive green roofs
• Intensive green roof</td><td>
Figure 14: Green roofs of lightweight structure for Triodos Bank in the Netherlands (Triodos Bank / RAU, 2019)</td></tr>
<tr><td>Green screens</td><td>The application of vertical greenery features for existing exterior of buildings envelopes.
• Green tree/climbing barrier systems
• Green climbing/modular coating systems
• Green walls
Mur vegetal/light systems/heavy systems</td><td>
Figure 15: A vertical greening system of the living wall for Quai Branly Museum designed by Patrick Blanc (Della Maggiora, 2024)</td></tr>
<tr><td>Air envelopes</td><td>The air layer surrounding the building exterior envelope for existing facades and roofs.
• Enclosed type
• Naturally ventilated type
• Mechanically ventilated type</td><td>
Figure 16: The double skin façade of Cambridge Public Library (Carey & Bergeron, 2022)</td></tr>
</table>

	Water walls	The water wall system WWS includes strategies for using water as a spray or through water pipes applied to the building's exterior envelope. • Pipe water wall • Spray water wall • Water-based materials	 **Figure 17:** The fluid envelope walls-roof-floor of the Water House by Matyas Gutai architect (Thakur, 2015)	
	Natural materials	The focus on utilizing natural-based materials for retrofitting procedures of siding and shading for building envelope. • Thermal insulators • Cool roofs and envelopes • Biomaterials louvers	 *Siding:* Bamboo poles for garage in Netherlands  *Shading:* Vertical wooden louvres for Asakusa parking information center in Tokyo **Figure 18:** Different applications of nature-based materials in building exterior design (Kirimtat, Koyunbaba, Chatzikonstantinou, & Sariyildiz, 2016)	
	Organic patterns and forms screen	The organic screens for aesthetical configurations of cladding and shading devices. • A form as a ration • A form as a whole closer to nature • A form as a whole	 **Figure 19:** The Italy Pavilion in 2015 Milan Expo (Italy Pavilion Milan Expo 2015, 2015)	**Natural analogues**
Building Context	***Open space***	The functioning of spaces in the building context. • Activity-recreational/passive • Size- small/large gathering • Form- spaces shaped by buildings/ building's forecourts • Spiritual aspect-symbolic/discovered spaces	 **Figure 20:** Campus for Research Excellence and Technological Enterprise, Singapore (CREATE - Campus for Research Excellence and Technological Enterprise / Perkins+Will, 2015)	**Nature of the space**
	Overhead canopy	The shaded walkway for the building approach and facades. • Horizontal/vertical cladding • Opaque/transparent material • Configuration structure • Climbing greenery	 **Figure 21:** South Beach, Singapore (Vial, 2019)	
	Green shady	The appropriate specification of trees promotes qualities for building envelope environmental and aesthetic requirements. • North greenery • East and west greenery • South greenery	 **Figure 22:** Outdoor greening of Shenzhen College of International Education, China (Shuangyu, 2021)	

	Nature-inspired solutions to the local context	The bio-inspired concerning the urban context of the building • Nature as model • Nature as measure • Nature as mentor.	 **Figure 23:** Metropol Parasol, Seville, Spain (Partner, n.d.)	**Natural analogues**

5. Case study

The research outputs of aesthetic and environmental indicators are applied to the skin of the administration building and the Faculty of Engineering at Delta University for Science and Technology in an attempt to allow the existing building to integrate with the natural environment, become environmentally friendly, and achieve positive aesthetics.

5.1. Overview

The case study is an academic five-story building of the Faculty of Engineering with a ground floor and four typical floors. The roof comprises a flat slab with skylight openings for atriums and a services extension. The building skyline has sloped roof sheets above the extension of the services. The northwest facade has the building approach and accesses three main entrances.

- **Geographical location**

Figure 24: Geographical Location of the Administrative Building of the Faculty of Engineering, 2022

- **Building architecture**

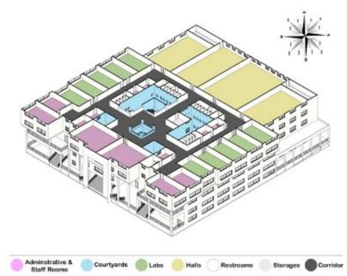
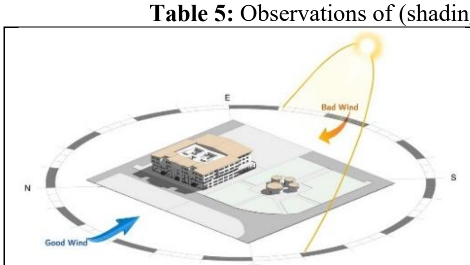


Figure 25: Picture from Reality of Administrative Building of the Faculty of Engineering, 2022
Figure 26: Typical floor Zoning Administrative Building of the Faculty of Engineering, 2022

- **Environmental setting**

Table 5: Observations of (shading – natural ventilation -natural lightening) for case study building

 **Figure 27:** Revit modeling for the case study	– The southwestern and southeastern façades are the most exposed to the sun with window openings for classrooms and halls for natural light.
	– Window openings on the fourth floor appear at a higher seating height than the others, which negatively affects the distribution and movement of air within the spaces.
	– The southwestern facade has light glare entering from the windows of classrooms, some with curtains from the inside to reduce light glare.

5.2. Green transformation

The natural solutions applied to the building skin analyzed as a building envelope consist of a flat roof slab, sloped roofs, a northwest facade, two south facades, and a northeast facade. This classification of the building exterior is considered as the reference for the applied green transformation solutions.

- **Environmental concept - Urban Microclimate**

Creating Urban Microclimate for the building envelope involves designing green aisles in the south direction of negative pressure and north wind airflow. The characteristics of trees influence wind flow for a better natural ventilation and indoor environment quality, as explained in Figure 28.

Figure 28: A schematic of the environmental concept applied to the case: existing building envelope

- **Strategies outline**

The elements of the envelope influence the targeted visual and environmental design practice for applying natural solutions toward the green transformation of this academic building's exterior. The roof transformation is a green vertical and sloped roof. The northwest facade gets greened first-floor terraces and the ground-floor well to reinforce the soft scape presence. Moreover, the green aisles aligned the facades followed by a shaded pathway of overhead canopy. In the context of the southwestern facade, the walkway has the overhead canopy as a protected area and provides a social space. Both the south facades had the super-tree groves manifesting the aesthetics of the green wall. The essential design factor that merges these natural preferences considers the outdoor connectivity with the existing landscape features. Hence, the protected area acts as a buffer between the educational building and the recreational spaces of cafeterias, as shown in Figure 29.

Figure 29: Final passive strategies for case study building

- **Strategies record**

Table 6: The presentation of the applied natural-based transformation strategies

Design scale	**Design indicators**	*Microclimate (green aisles)*
Building envelope	*Air walls*	

	South facades screens	
	Green roofs	
Building context	*Open space*	
	Overhead canopy	
	Green shady	
	Nature-inspired solutions to the local context	

6. Conclusion

One of the challenges facing sustainable development is to achieve the necessary patterns of interaction with the human-made environment and nature. Buildings deserve special attention for their significant contribution to environmental and health problems. The concept of sustainable (green) building is a modern response to address the problems resulting from the construction sector. The research has developed a set of aesthetic and environmental indicators for the building envelope (skin) based on integration with the natural environment to transform them into green buildings that are environmentally friendly, achieve positive aesthetics filled with movement, and change and include a dynamic process instead of fixed objects. Thus, the research has managed to overcome some of these challenges and shed light on opportunities and barriers to push the green construction agenda forward.

Disclosure
The author reports no conflicts of interest in this work.

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