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Biomimicry In Eco – Sustainable Interior Design: Natural Ventilation Approach

Doaa Ismail Ismail Attia

Lecturer of Interior Design and Furniture, Faculty of Applied Arts, Benha University

Abstract:

Nowadays the biomimicry solutions for interior design problems is an obligation rather than a wish to satisfy human needs and quality of human life . In this research study , biomimicry technology is used to formulate a “breathing window” model to enhance the natural ventilation as a way of curing the ecological and sustainable balance by providing social , culture, environment, and economic progress.

The proposed model is based on using the biomimicry approach; “designs looking to biology” to emulate the structure form and function task for chosen natural organisms; Human nose, Bee’s honey comb, and Cacti cooling plant. This emulation can be actuated through using different natural phenomena’s: evaporative cooling, shading, and changing light to heat, which natural organisms used to adapt themselves to the surrounding climate. The “Breathing Window” consists of steps with specific feature and task. In summer: increases shade , reduce heat gain around and on window by reflecting direct sunrays then , cool and filter air flow passing through window using evaporative –cooling phenomena. In winter; it filter air, permits direct sunrays to pass through window, spreading light and heat, in the far interior environment .

The “Breathing Window” adding to cooling interior air in summer and warming it in winter ,filter air from micro particles and dust , maintain the aesthetic design appearance , reduce: used material , energy , weight ,pollution and cost ,also easy to clean ,well-being of occupant ,and rating sustainability in interior environment .

Keywords:

- interior design ,
- biomimicry design,
- eco-interior design ,
- natural ventilation ,
- sustainability ,
- renewable energy ,
- Breathing Window

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Introduction

Natural organisms interact with the environment in a successful and sustainable way, without depleting natural resources or polluting the environment . They designed highly efficient biological systems that can adapt themselves to the surrounding environmental conditions in order to overcome different challenges .

Biomimicry has the purpose of designing to emulate and integrate with natural systems when planning for a human design with the aim of reducing : energy , material , weight , cost and pollution. Interior design tried to imitate nature to enhance and improve its capabilities. It started with imitating figures, forms and structures . It was until the end of the 20th century, when it became possible to imitate nature’s process, function and ecosystems in designs .(10)

The research paper, tries to benefit from the availability of biological information about some chosen natural organisms which give us ideas, in order to emulate its design solutions by looking at its form ,structure, material ,process and function , to create optimal restorative solution to solve one of the important challenges in ecological interior design, that is thermal comfort. This can be

achieved by enhancing natural ventilation in the interior environment by reformulating a new proposed model for “Breathing Window” :that emulate the human nose which modulates the air before entering to bronchi by cooling it in summer and warming it in winter . This modulation process can be actuated through mimicking: structure form, process and functional task of the human nose, the bee’s honey comb and the cooling cacti plant. Different ways that natural organisms used for self adaptation with the surrounding environment as: evaporative cooling , shading , and converting light to heat (fiber optic)are also considered

The idea of modulating atmospheric air before entering to the interior environment through windows by evaporative –cooling phenomena was first introduced by ancient Egyptians(1300B.c) ,then during the Islamic era (12) and later by the architecture “Hassan Fathy” in the “Breathing Wall”,(1986)(3), and by Nottingham university in using “modular porous Ceramic cuboids” , (2004) (12). Nowadays the green –facades systems are new techniques using evaporative –cooling phenomena to decrease thermal effect (17)

Research problem:

- In closed buildings as: work places, education places, hospitals, people habitations ..etc ,which are mechanically ventilated ,people feel locked up and suffer from the sick building syndrome. These complaints are sufficiently remedied by the opening of windows.
- The amount of electricity and energy used for air conditioning is huge .
- Increasing environmental pollutants due to burning out coal or gas to run the air conditioners.

Object of research:

To find a Biomimicry sustainable eco- interior design solution to enhance the efficiency of natural ventilation in interior environments with minimum usage of material, energy consumption, pollution and cost, to obtain good health impact on the human body.

Research methodology:

The research follows the analytic, descriptive method to acknowledge the elements of the research problem in trial to find a design solution for it.

1- Natural Organisms Structure Forms

a- Fundamentals of structure forms for natural organisms;

- Creation of maximum strength with minimum input material:

Nature employs a relatively small amount of materials in its assemblies as compared to human constructions. However, through unique configurations of these simple materials ,nature is able to create structure that out perform many man-made structures (6). For example ,bones, in natural organism, shows variation in their cross-section all over their length, to deposit the material where it is most needed . In addition, cross-linking of the fibers in the bone contribute to the increase in strength without a corresponding increase in weight or material (Fig1).(6)



(Fig 1): creation of maximum strength with minimum input material in human bones.

- *Dissipation of multidirectional forces through curvilinear structure forms*

The use of curvilinear structure forms in the natural organism requires less input of materials and thus reduction of weight . It also has the ability to absorb and dissipate multidirectional

forces. For example ; the structure form of the moving organism is often tailored in curvilinear form to maximize efficiency to resist environmental stresses with the minimum amount of mobile energy .fig(2,3, 4)(6)



(Fig 2) (Fig 3) (Fig 4)
(Fig 2,3,4) Dissipation of forces through curvilinear structure form.



(Fig 5) Stress and strain for efficiency of structural form of leaf.

- *Usage of stress and strain as a base for efficiency of structural form :*

Final structural forms for natural organisms are dependent on varying rates of growth and the product of its response to the environment and the properties of the material used, as well as the genetics that define the growth template while stresses are acting on and within the organism structure form (Fig 5) (6)

b- Basic geometric structural forms for organisms in nature:

The structural forms for natural organisms and their shelters are composed of a set of basic geometric forms where each organism uses them in different proportions and complex ways(Fig 6) . For example : **Curvature form**; skulls , birds , bird nest cactus, **Columns, tubular , Cylindrical form**: tree trunks , long bones , **Corrugated form**: scallop shells, cacti plant, leaves of some plants , **Parabolic forms**, pine apple , cactus plant , **Tension membranace forms**: silkworms webs, spider webs , **bell form** : bee 's honeycomb as well as **Spirals form** : heart of sunflowers, shells . (14)



Cacti plant scallop shells Shell
Fig 6a



sun flower pine cone Bee’s honey Comb

Fig 6b



leaf of plant skull Cactus plant

Fig 6c

(Fig 6) Different geometrical structural forms for natural organisms.

c-Characteristics of natural structure forms:

In general they are characterized by being Strong, flexible, aesthetic, using minimum amount of material stable against forces, least construct

energy , with maximum storage places , minimum weight and least cost. (14)

2- Biomimicry in interior design and furniture:

a- Principles of biomimicry

The principles of biomimicry are those of nature inspiration:

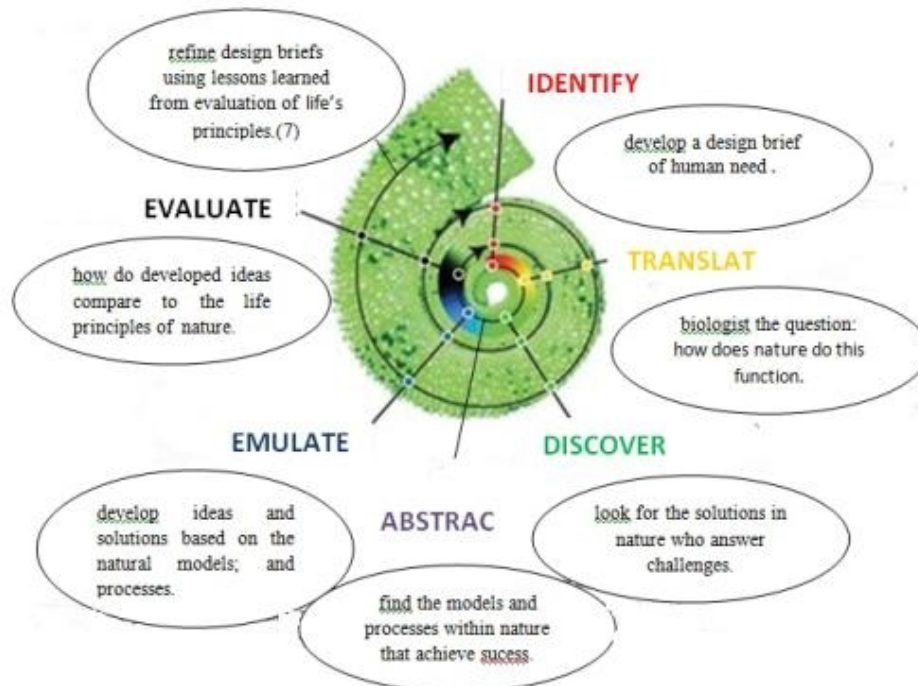
Nature; runs on sunlight ,uses only the energy and resources that it needs , always fits form to function, recycles and finds uses for everything, reward cooperation, depends on and develops diversity, requires local expertise and resources , avoids internal excesses, taps into the power of limits (4)

b- Biomimicry as model ,measure and mentor

Model : studies nature’s models and emulates their designs and processes to solve human problems.

Measure: uses the laws of nature, its strategies and principles as a standard to judge the “rightness” of our innovations . Mentor; is a new way of viewing and evaluating nature, based on what we can learn from it not on what we can extract from it. (4)

c- Biomimicry design spiral;



(Fig 7) Biomimicry design spiral. (4)

d- Benefits of biomimicry in design;

It helps to create processes that are inherently more sustainable , perform better, use less energy , eliminate waste, reduce material , minimum weight and cost, also create new and efficient products .(4)

e- Biomimicry in design process :

Biomimicry as a design process is divided scientifically into two approaches;

“**Biology influencing design**” which demands scientific analysis of biological system, so it needs a cooperation between biologists and designers”, or “**Designs looking to biology**” which deals with creating new designs by looking to the biological behavior , structure form and function of natural organism and ecosystem in order to study how they overcome the same problem that designers faced in their designs.(11)

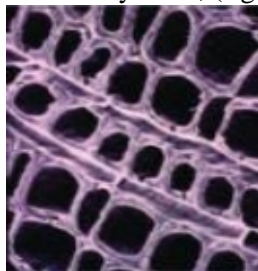
Within these two approaches ,designs could be biomimetic in terms of three possible dimensions : first; physical components (**form**-what it looks like, **material**-what it is made out of ,**structure**-how it is made . Second; **function** – what is able to do and **process** – how it works . Third ; **ecosystem**. Most of the existing design examples are related to: form, structure , material and in a lesser extent to functional tasks , while it is difficult to find design examples in ecosystem(10).

f- Optimal natural structure forms used in interior design :

In what follows, we consider optimal structure forms with minimum input material and maximum strength and are the most interesting to mimic from nature to interior design and furniture.

• **lattice structure form**

A set of grouped opening which are covering a surface , provide a structure form with high strength , light weight, resistant to both tensile and compressive forces. then allow flexibility and beauty ,also inherent stability . (Fig 8) Ex: a plant (Fig 9), inside our bones (Fig 1) , hexagonal bee’s honeycomb, (fig 6)



(Fig 8) lattic structure form



(Fig 9) lattic structure form for a plant .

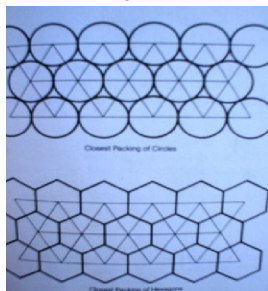


Fig 10: Triangulation of two-dimensional closest packed arrays.

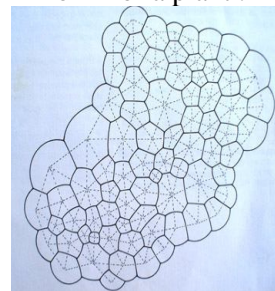


Fig 11: Triangulation of random bubbles viewed from above

The closest arrangement with equal spheres is equivalent to that equilateral triangular arrangement formed by joining the centers of spheres . The latter exhibits inherent geometric stability so is for closest arrangement with spheres. (Fig 10). If the circles are tightly packed as densely as possible with small concave triangles formed between circles , which match the least area with the greatest circumference . Therefore , this would be the arrangement which requires the

least effort to maintain their tendency in a triangular order (minimum energy configuration) (8) (Fig 10) . Therefore, the circle packing forms cannot be considered as the most economical system, since by considering the concave triangles , forming hexagons this become the most economical method for partitioning a surface into equal units area (Fig 12). For any lattice array, either random or uniform openings , it can be considered that the openings will be organized according to a triangular order and so the law of stability for the closest packing and triangulation can be seen .(Fig 11)



Fig 12a The lattice structure form for hexagonal, has minimum area, minimum material , no loss in area .Hexagonal perimeter=18cm.

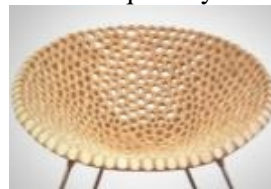


Fig 12b The lattice structure form for circles minimum, area, minimum material, exist loss in area. Circles perimeter =17.1cm



Fig 12c The lattice structure form for rectangles ,no loss in area , has large areas, use large amount of material. rectangular Perimeter =19,7cm

(Fig 12) Comparison between the different in lattice structure form : area, unused space and quantity of materials used .(9)



chair



basket



wall in a shop

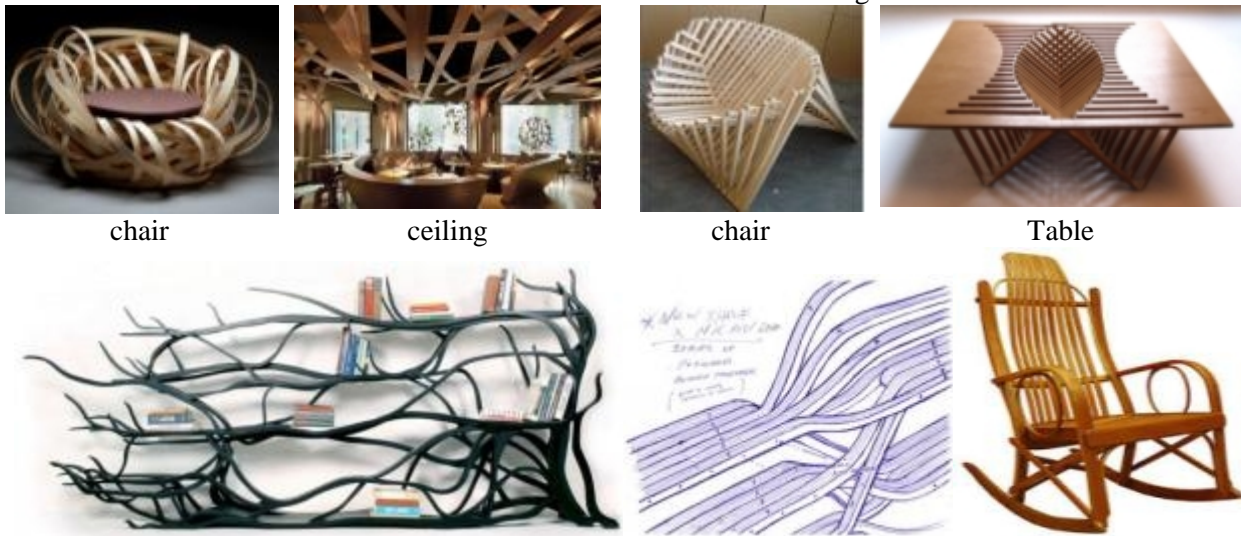


chair

(Fig 13) Different styles of interior design and furniture’

• **Cross and parallel-linked structure form :**

Minimal investment of material and weight that provides a maximum strength. Ex. :the bone in the human leg (Fig 1), the bird nest. s works using lattice structure form.



chair

ceiling

chair

Table

books shelf .

(Fig 14) Different style of interior design and furniture using the concept of cross and parallel -linked structure form

• **Curvature structure form:**

Living organisms that have curvature in their bodies structure forms to reduce enormous tension forces , makes it possible for the loads to be supported with the least amount of: effort, material, cost , weight, and cracks will also be easily dealt with . Ex. : the bones in our bodies, the forking of branches in trees (Fig 15) and the shells(Fig 4)



wo tables designed using the curvature structure form.



curvature in our pelvis



curvature in forking of trees bra

(Fig 15) Curvature structure form in nature.



A stair designed using the curvature, lattice openings, and cross-linked structure form



A design for ceiling and wall joined together by a curvature structure form .

(Fig 16)Different styles of interior design and furniture works using curvature structure form.

• Pleats or Veins structure form :

For flat with light surfaces, the introduction of a set of pleats or veins running through the direction in which bending is expected, increases the

effective thickness with only a little extra investment of material and weight. (14)

Ex: The veins in the structure form of the wing of an insect and plant leaf also the pleats in palm’s leaf structure form.(Fig 17)



Veins in plants



Veins in wings of insects



Pleats in the palm’s leaf.

(Fig 17) the pleats or veins structure form existed in different natural organisms .



(Fig 18) some ceilings designed by using the pleats or veins structure form.

• Iterative structure form:

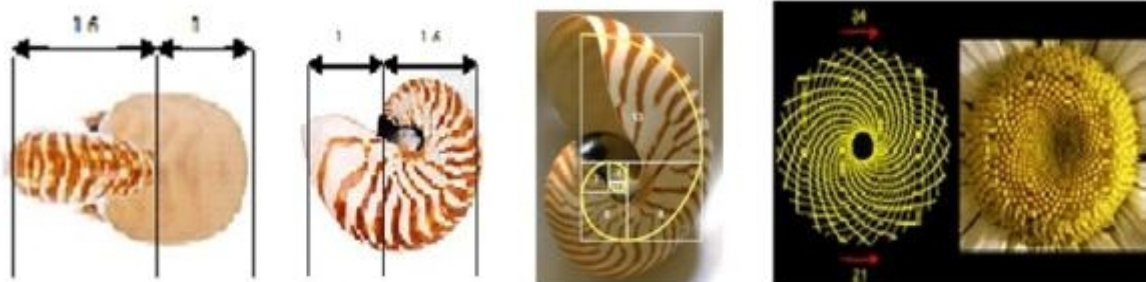
Essential light weight shape that can be iterated such that each one of these iteration will be similar to the original shape and getting more smaller in size. (Fig 19)



(Fig 19) some interior designs and furniture based on iterative structure forms.

• The golden spiral structure form:

The golden spiral structure form is based on satisfying the golden ratio 1:1.618 which is widely found in nature as in sun flower , shell .(Fig 20)



golden spiral structure form

sun flower heat. shell

(Fig 20) natural organisms have a golden spiral structure forms.



(Fig 21) some interior design and furniture based

3-The "Breathing Window":

The research work of "Breathing Window" follows the Biomimicry approach " designs looking to biology" which is emulating the nature by looking to its form, structure, material, process and function to learn how natural system can overcome the same design problem.

a-Method of design solution :

The method of design solution we consider depends on the following steps;

- Search one or more of natural organism which we believe that it include the ideas leading to the solution of our interior design problem.
- Study its form , structure and material to know its process and function.
- Thinking of the role of this organism in improving our interior design problem.
- Solve our problem by building a process which depends on the ideas we convince about the form , structure, material as well as the process of the natural organism.
- Define the initial study to include more complex detailing of components and connections to create a solution for the interior design problem with maximum benefits and minimum material , energy , cost and pollution.

b-Factors that natural organisms depend on to adjust its thermal system:

(i) Structure form and functional task for the chosen organisms:

- **Human Nose** (Fig 22) (18)

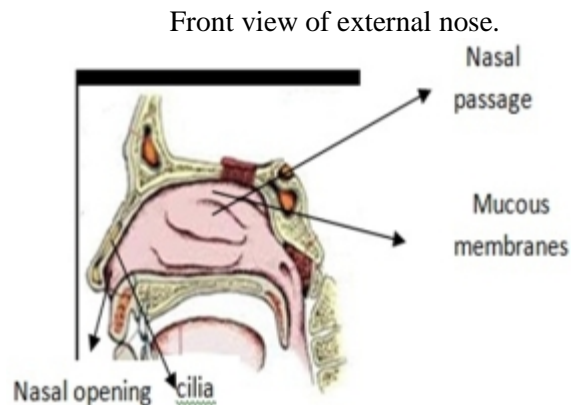
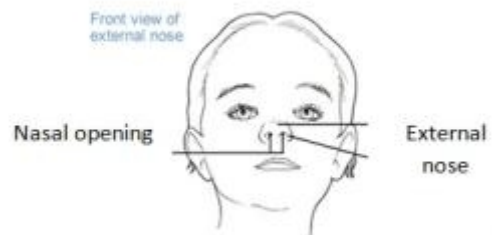
Structure form : Two exterior openings followed by nasal passages that are linked with mucous membranes , tiny hairs (cilia) and blood capillaries.

Functional task :The exterior openings permit the atmospheric air to pass through nasal passages which has the following functional tasks;

- Modulating the temperature of the atmospheric air passing from outside to the respiratory system by moisturizing it using mucous membranes which secrete a sticky

substance to cool hot air in summer , while using blood capillaries to warm cool air in winter.

- Filter the atmospheric air before passing further into the respiratory system by preventing entry of foreign micro particles using the mucous membrane and cilia.



(Fig 22) Human nose.(18)

- **Cooling cacti plant:**(Fig 23) (19)
- **Structure form:** ribs covered by thorny spines adapted on buds .
- **Functional task:** the role of ribs and spines are:
 - - Reflect direct sunlight to provide shade and enhance heat radiation to protect cacti from the sun.
 - - Allow the air to pass through , preventing dust and foreign particles.
 - -Absorb CO₂ from air.



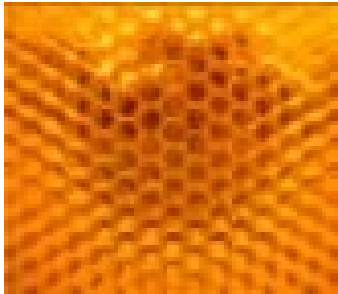
(Fig 23) cacti plant

Bee’s hexagon honey comb(21) (Fig 24)

Structure form: Hexagonal lattice structure form with minimum recycling material.

Functional task:

- Has a large volume enough to permit day light and air flow to pass through it.
- The structure form is inherently stable to struggle with the exterior wind force.



(Fig 24) Bee’s hexagon honey comb(12)

(ii) The ways natural organisms use to self adapt with the surrounding climate:

§ **Evaporative Cooling:** (hot environment) . Natural organisms feel cool by losing temperature through evaporation .Ex; stomates in plant leaves. (1)

§ **Avoiding heat gain:** (hot environment)

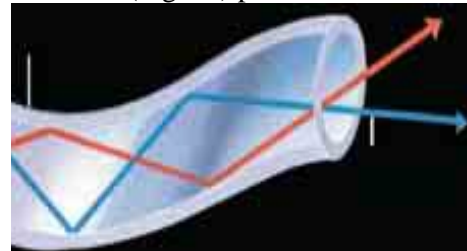
- Dense small plant leaves of the spines and hair instead of large leaves, to decrease the surface exposed to direct sunlight , while allowing the fresh air to pass through it. (2)
- Rotating leaves which enable the plant to direct its leaves away from maximum exposure to the sunrays. (1)
- Having ribs with its shapes that provide shade and enhance heat radiation(19).

• **Transmit light into heat - fiber optic capability** (cool environment):

The polar bear is able to keep its body warm even under the freezing polar conditions since its fur carry the rays of the faint polar sun directly to the animal’s body because the fur possesses fiber optic capabilities where it converts light into heat thus it helps to warm the bear’s body.(Fig 25)(7)



(Fig 25) polar bear



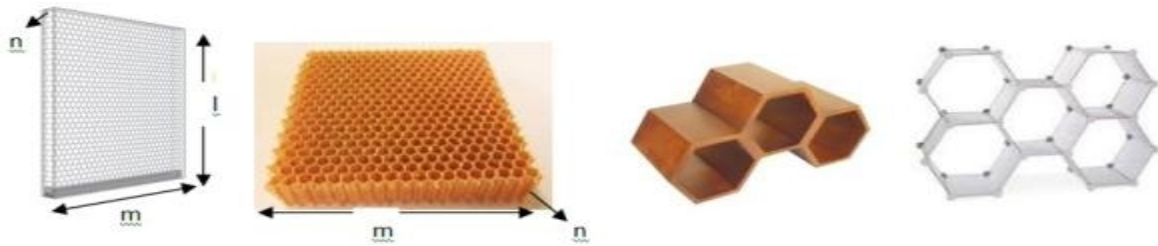
(Fig 26) fiber optics cable.

Fiber optics are transparent glass cables for transmitting light . Since optical fibers can be easily bent and twisted they can ‘pipe’ light into even the most inaccessible locations and also transmit light into heat .(Fig 26)

c- “Breathing Window”: Structure form and functional task.

Structure form: (Fig 27)

A body has a parallelogram shape with dimensions n,m,l has the structure form of the bees lattice hexagonal honey comb .It has two mxl vertical symmetric exterior and interior hexagonal lattice shape facades , between them exist identical horizontal parallel hexagonal passages of length n on top and close to each other, permitting exterior atmospheric air to passé through to the interior environment . The envelope of the breathing window consist of four joined pipes having a parallelogram shape; two nxlxp right and left vertical pipes and the other two nx mx p upper and lower horizontal pipes having small opens on the two nxm sides facing the interior hexagonal passages . The four pipes are made from a non-moisturizing and non-rusting metallic material . the body hanged outside the window at a small distance from the wall and stand on a non-rusting metallic plate.



(Fig 27) The structure form for the “Breathing Window”

Functional task:

In the interior environment; the breathing window filters the atmospheric air, Cools it in summer and warm it in winter.

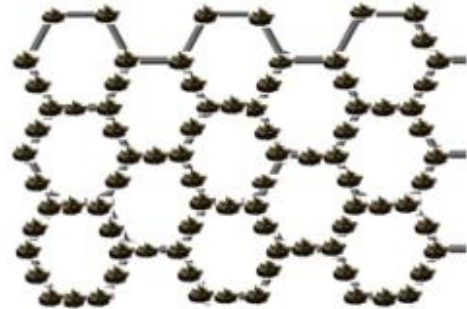
In summer : Takes place via two steps:

First Step; Increases shade, reduces heat gain, and filters atmospheric air

A metallic framed panel with hexagonal lattice shaped identical with the exterior façade and hanged on it (Fig 28), The panel has metallic pockets to cultivate small sized cacti plant which is put in a felt curtain irrigated through dripping. The felt holds a substantial amount of water which allows the roots to remain always moist (20). Cacti plant is a desert plant which needs small amount of water. The functional task of cooling cacti plant includes reducing heat gain, increasing of shade area around and on the window, filtrating of atmospheric air from foreign micro particles and preventing emission of toxic gas CO₂.

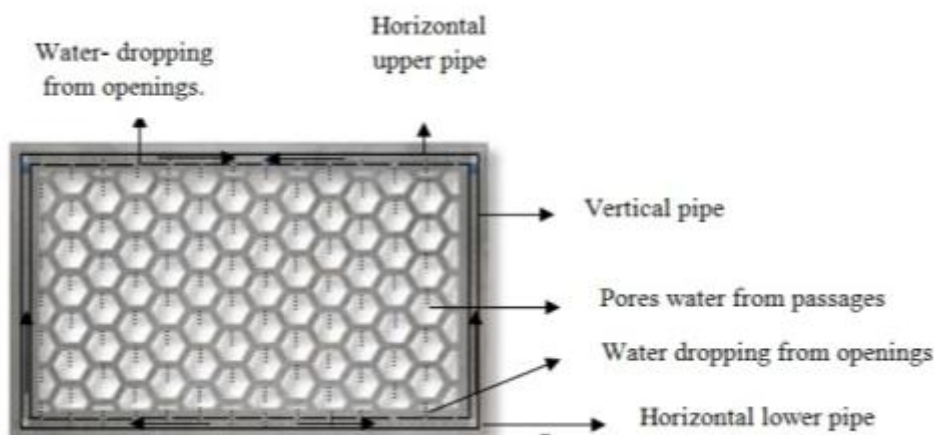
The hexagonal passages are made of natural material as textile, clay or reeds which has porous feature to absorb water vapor from the atmospheric air and filter it from foreign particles. The atmospheric air passing to the interior

environment is now cool and pure. The water absorbed by the hexagonal passages pass, as drops through the pores of the textile, clay or reeds from upper passages to lower ones and finally through the openings to the lower horizontal pipe, which when full, moves water upwards through the two vertical pipes using the theory of pounding utensils then to the upper horizontal pipe. The water will be reused once again by passing through the opens in the upper horizontal pipe to the hexagonal passages thus helping in the evaporative cooling process. (Fig 29)



(Fig 28) frontal view for the metallic framed panel, with cooling cacti plant in pockets

Second Step: Evaporative-cooling and filtering atmospheric air:



(Fig 29) In summer; a frontal sector to show how the water drops directed from the hexagonal horizontal passages to horizontal lower pipe, to vertical pipes then dripping once again from the horizontal upper pipe

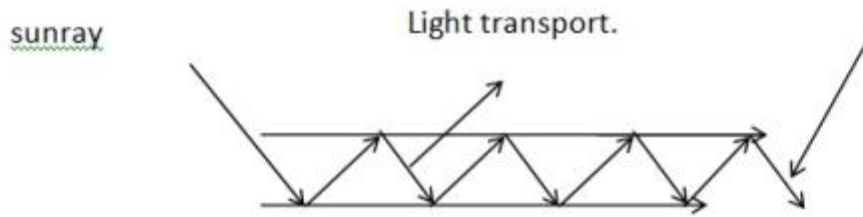
In winter; warms, and filters the atmospheric air

The hexagonal passages are made of a fiber optic material or any other reflecting material with

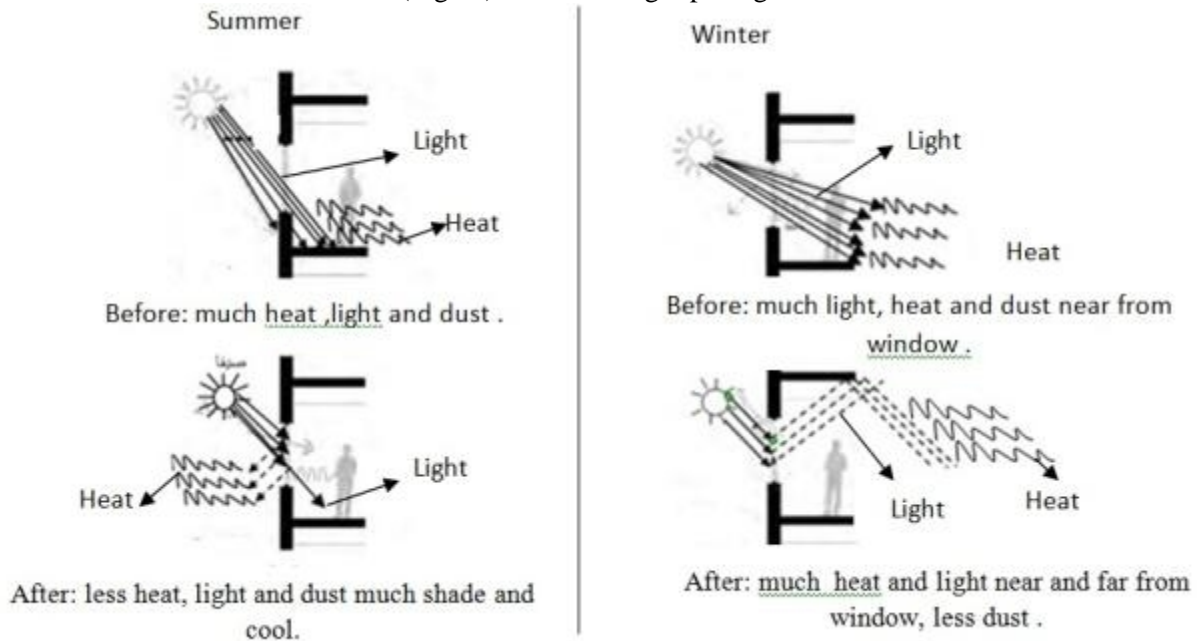
minimum weight, is covered by a sticky transparent substance. The passages reflect the sunrays coming from outside to the far interior environment (Fig 30) and permit purified

atmospheric air to pass as the foreign micro particles stick on the passages surface , thus,

heating and filtering air in interior environment (Fig 31).



(Fig 30) horizontal light passage.



(Fig 31) the intensity of light and heat before and after using “Breathing Window”

d- Sustainability in interior environment

The “Breathing Window” plays an important role in achieving sustainability in interior environments.

- **Material aspect.**
- The materials used in “Breathing Window” are natural materials that have the potential for unlimited recyclability, renewability, less emission of toxic gases and pollution.
- The lattice hexagonal structure form of the” Breathing Window” uses minimum: material, energy and cost.
- The collected water, through the evaporative –cooling process ,is reused.
- The cultivated cooling cacti plant on the exterior facade is an example of using natural green materials in ecological design in the interior environment.
- The natural material used in the passages has porous feature which is used in the

evaporative cooling and filtering air process.

- **Daylight aspect;**
- “Breathing Window” permits the passage through interior environment a small amount of sunlight in summer versus large amount of sunlight in winter into the interior environment . (Fig 31)
- The daylight has an essential role in developing resource sustainability (sun light), economical sustainability (reduced. energy)and health sustainability (better human physical and psychological) in interior design.
- **Social aspect**
- Modulating ventilation in interior environment using the “Breathing Window “ obligate the user to stay long time in the space so create a complex intimate interaction between the person and the space in the social aspect.
- **Heritage Cultural aspect**
- The evaporative-cooling phenomena is a heritage cultural aspect since ancient Egyptians(1300B.C)who put a wet cloth in front

of the window to cool the breeze passing through it as proven by drawing in tombs in Luxor.(12).It developed and harnessed further during Islamic Era who put porous pottery and clay jars filled with water in plates on the balcony or window boundary to cool both the water in the jar and the atmospheric air passing to interior environment(12) . In (1986) evaporative cooling is used in “Breathing Wall” by Egyptian architect “Hassan Fathy” (3) . Later , it is used with the green facades systems to decrease thermal effect.(17)

- **Economic aspect:**

- The materials used in the "Breathing Window" are natural, local, recyclable and so cheap.
- Using the sun and wind as a source of renewable energy.

e-A computational Iterative method to achieve a Biomimicry design solution with certain accuracy:

In what follows we consider a computational iterative technique to achieve biomimicry design solution with a certain accuracy. This technique is a base for a computer program includes a number of subprograms to evaluate emulated : material, structure form and function task.

The spiral biomimicry design solution diagram (Fig 7) represents an iterative procedure where every complete round give a biomimicry design solution for a considered human problem emulating a natural design solution for the same problem in nature . The biomimicry design solution must converge to natural design solution when the number of rounds (iterations) go to infinity. This means that the biomimicry design solution will never coincide with natural design solution, but converges to it to a certain accuracy . The convergence of the biomimicry design solution to the natural design solution depends on the convergence of S_B , f_B , m_B to S_N , f_N , m_N , where S_B , f_B , m_B & S_N , f_N , m_N are representing the structure form, the functional task and the used material for both the biomimicry design solution and the natural design solution, respectively. The considered computational iterative technique depends on giving the physical features of m_B , S_B , f_B and m_N , S_N , f_N corresponding numerical values . Let $\delta_m = m_N - m_B$, $\delta_s = S_N - S_B$, $\delta_f = f_N - f_B$, where $e \equiv (\delta_m, \delta_s, \delta_f)$ represents the error vector & $\|e\| = \max |\delta_i|$, $i= m,s,f$ represents the size of e (5). Consider e_n is the error vector in the spiral round number n . Then the biomimicry design solution converges to natural design solution if $\|e_{n+1}\| < \|e_n\|$, so $e_n \rightarrow 0$ as $n \rightarrow \infty$.

Provided that the iteration process stopped when the size of the error vector of the biomimicry solution achieve **the accuracy ϵ^*** we summarize the technique in the following 5 steps.

- 1: develop appropriate questions from nature principles for m_B , S_B , f_B , go to 2.
- 2: consider their numerical values to evaluate δ_m , δ_s , δ_f and evaluate ϵ . go to 3.
- 3: if $\epsilon \leq \epsilon^*$ go to 5, otherwise go to 4
- 4: Identify new more precious questions from nature principles to explore and develop more to improve and refine m_B, S_B, f_B go to step 2.
- 5: Accept this biomimicry design solution.

4-Result:

- The “Breathing Window “presented in this paper is a model for sustainable natural ventilation in interior design: where it is a replacement for the traditional mechanical ventilation systems, thus increasing the sense of belonging and attachment to the local: place, heritage and culture.
- Provides good and clean natural ventilation with suitable light through the interior space by cooling air with less light in summer and comfortable heat and enough light, in winter, through the right usage of the openings.
- Maintains the aesthetic design appearance, easy to clean, and introduces thermal comfort and good health for the human body.
- Satisfies sustainable aspects in interior design: environmental (material – daylight), social; (intimate relation between the user and the interior environment), cultural (using evaporative-cooling technique .)and economical (Reduces energy consumption, used material and cost .)

5- Conclusion:

- Nowadays, The world is facing two problems: the energy problem and the nature resources depletion problem. The “Breathing Window “creates a design solution for ventilation problem in interior environment as nature does thus, it will be having a great efficiency as it reduces energy since using **renewable energy** : natural sunlight & wind and **local recycling natural material** : clay or

reeds or textile and metal ,and so reduce the amount of waste.

- One of the impressive natural processes is the ability of climatic adaptation with the surrounding climate which we notice in Human nose, Cacti cooling plant and Bee's honey comb using their physical characteristics & behavioral reactions which are taken into consideration when regulating the temperature of the breathed atmospheric air .

-The “Breathing Window” acts as an adaptive window which promotes a biomimic sustainable natural ventilation solution in interior design that modulate atmospheric air by cooling and warming interior environment also controlling the spreading of light, thus assuring the thermal comfort for occupant .

6- Recommendations:

a-In future, there is a need for young interior designers to create bio-inspired design adaptations that emulate nature's best ideas so that all futuristic interior design and furniture be sustainable.

b- While the biomimicry is getting known, to understand how nature works out these issues, the biologists, scientists and mathematicians consultants are getting their important role with designers, and as a result the biomimicry solutions become close enough to nature.

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