BIOMIMICRY IN ENVIRONMENTAL ARCHITECTURE

EXPLORING THE CONCEPT AND METHODS OF THE BIO-INSPIRED ENVIRONMENTAL ARCHITECTURAL DESIGN

by

Ayat Abdul Rahim Al-Jawhary Ahmed Sheta

A Thesis Submitted to the Faculty of Engineering at Cairo University

in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

In

ARCHITECTURAL ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
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UNDER THE SUPERVISION OF

Prof. Dr. Baha'a El Din Hafeth Bakry	**Prof. Dr. Ahmed Ahmed Fekry**
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Approved by the Examining Committee

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FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
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LIST OF SYMBOLS AND ABREVIATION

BID: Biologically Inspired Design

F: Contradicting Feature.

IP: Inventive Principle.

FORWARD

To the soul of my mother, to my family,
to those who had ever taught, encouraged and inspired me,
and to all those who dream of a scientific awakening for our countries.

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All praise to ***Allah the almighty***,
Who alone made this small objective accomplished.

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ABSTRACT

Nowadays, there is a growing interest in Biomimicry, as a new discipline that looks to nature as a model and mentor, and also in biomimetic methods of design. Most of which, is BioTRIZ, a conflict resolution database that is based on the study of natural ways of unfolding contradictions. This work aims at exploring the concept of Bio-inspired design and its different methodologies, in order to present a systematic way of problem solving, to reach more efficient built environment that mimics the efficient techniques, which are, day by day, being discovered in God creatures.

An application of solving a proposed design problem with TRIZ and BioTRIZ was performed.

NEW TERMS

This work has tackled a range of new terms that will be viewed in the following part:

- **Biomimicry-Biomimimetics-Bio-Inspired Design (BID):**

The study of the mechanisms of natural living organisms, to perform their functions.

- **TRIZ (Pronounced 'Trreeez'):**

Russian language acronym for 'Teoriya Resheniya Izobreatatelskikh Zadatch', the acronym is usually translated into 'The theory of creative problem solving' (1).

It is a Russian system of engineering problem solving, made up of several problem-solving tools.

One of the most popular tools is a look-up table made up of 39 opposing features (parameters, variables) of engineering systems such as strength, weight, speed, volume, temperature, ease of manufacture and versatility.

If we define our problem in the right terms, the TRIZ contradiction matrix will point us to a set of inventive principles that have been used by other inventors to resolve our contradiction.

The inventor, or may be, the discoverer of the theory, a mechanical engineer "Genrich Altshuller", and his colleagues found 40 such inventive principles, (IPs), from the study of 3 million patents.(2)

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(1) Spain, E., "TRIZ Uncovering Hidden Treasures".

(2) Craig, S., et al., "Tow New Environmental Building Technologies, One New Design Method: Infrared Transparent Insulation, Biodegradable Concrete Formwork and Bio TRIZ".

- **Contradicting Features (F), Parameters, or Variables:**

  Sometimes, when we try to solve a problem by making something stronger, we find out that it had become heavier, we then use a different material but that makes it more expensive.(1) The contradicting parameters or features are those that when we try to improve one of them, the other gets worse.

- **System Conflict or Contradiction:**

  A system conflict is present when the useful action causes simultaneously a harmful effect, or when the introduction of the useful action, or reduction of the harmful action causes deterioration or unacceptable complication of one of the "system's parts" or of the whole system

- **TRIZ 40 Inventive Principles Matrix:**

  Genrich Altshuller was able to identify what inventors had done to stop one parameter getting worse at the expense of the other. By analyzing the patents, he found out that inventors always use the same strategies to solve the same contradictions. These strategies are called: the '40 inventive principles'.

  He then drew up a matrix in which both axes are the same: the 39 competing parameters. Where a column and row intersected, he placed the 'inventive principle' that was used to enable the improvement-on the vertical axis-to be made without making the conflicting parameter, on the horizontal axis, worse.

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(1) Spain, E., "TRIZ Uncovering Hidden Treasures".

- **<u>PRISM:</u>**

Russian language acronym for "Pravila Reshenija Izobretatel’skih Zadach Modernizirovannye" translated as ‘The Rules of Inventive Problem Solving, Modernized’. (1)

It is a new 6x6 version of the TRIZ contradiction matrix. Instead of the 39 features, the PRISM deals only with six features, Substance, Structure, Energy, Information, Space and Time.

- **<u>BioTRIZ:</u>**

Biological Version of the PRISM matrix. Based on analyzing the natural world instead of the inventions of mankind.

The same as PRISM, it is 6×6 meta categories or (Operational fields), those are: Substance, Structure, Energy, Information, Space and Time.

IF we define our problem in the right terms, the BioTRIZ matrix will point us to a set of inventive principles that is used in Nature to resolve our contradiction.

---

(1) Vincent, J., et al., "Biomimetics: Its Practice and Theory”.

Introduction

DESIGN INSPIRED BY NATURE

بسم الله الرحمن الرحيم

"قال فمن ربكما يا موسى *

قال ربنا الذي أعطى كل شيء خلقه ثم هدى"

صدق الله العظيم

.. الآية -٤٩–٥٠ سورة طه.

“49. There Pharaoh said defiantly,
Who is the Lord of you two, Mûsâ??
"50. Our God, Allâh the Lord, Mûsâ said, is He Who gave
form and features to every entity He created
(and vested each entity with its qualities and attributes),
guiding each creature to its inherent role in life.

… Ta-ha- Verse 50-49

Introduction

Design Inspired by Nature

- I. Biomimicry or Biomimetics
- II. Biomimetics Inventions
- III. Terminology
- IV. Inspiration in architecture
- V. Why biomimetics
- VI. Pioneers of the new discipline
- VII. The Goal
- VIII. The Objectives
- IX. Thesis structure

Introduction

DESIGN INSPIRED BY NATURE

Design Inspired by Nature

The word "bionics" is defined as: “The application of biological principles to the study and design of engineering systems (1)”. The growing interest in bionics was the motive to explore how the biological principles could be applied to architecture. During the early steps of this research, the word “bionics” was a misleading keyword, but the research led to the words: "Biomimicry" and "Biomimetics" that both have a closer relation to the world of architecture.

I. Biomimicry:

Biomimicry is a new discipline that studies nature's best ideas and then imitates these designs and processes to solve human problems. Studying a leaf to invent a better solar cell is an example.

It is "innovation inspired by nature” (2).

II. Biomimetic Inventions:

- **Velcro:**

In 1948, the Swiss engineer George de Mestral was cleaning his dog of burrs picked up on a walk when he realized how the hooks of the burrs clung to the fur (3). This led him to invent the “Velcro”; a fastener, widely used today.

Figure (i-1): “Velcro”, Registered Mark Fastener Inspired by Burrs Being Stuck to the Fur of a Dog
(http://www.mnn.com/earth-matters/wilderness-resources/photos/7-amazing-examples-of-biomimicry/burr-velcro#)

Figure (i-2): Closer Image to the Burr Seed (Left) and the Velcro Fastener Hooks and Loops (Right)
(http://biomimetic-architecture.com/page/3/)

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(1) http://www.answers.com/topic/bionics
(2) www.biomimicryinstitute.org
(3) www.wired.com/science/discoveries/news/2004/11/65642?currentPage=all#

- **Cat's eye**

Cat's eye (1) reflectors were invented by Percy Shaw in 1935 after studying the mechanism of cat eyes. He had found that cats had a system of reflecting cells, known as "tapetum licidum", which was capable of reflecting the tiniest bit of light."(2)

Figure (i-3): Cat's Eye
(www.bre.co.uk)

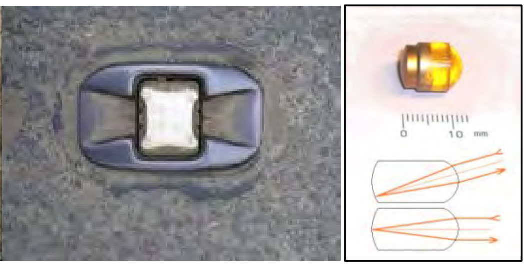

Figure (i-4): "Cat's eye" Registered Mark Inspired by the Eyes of Cats
(www.wikipedia.com)

- **Gecko Tape:**

According to Ge et al., (2007) (3) a synthetic gecko tape has been developed, based on the hierarchical structure found on the foot of a gecko lizard. The pad of the gecko toe is crossed by edges covered with hair-like stalks called setae, which branch into hundreds of tiny endings. Gecko toes stick to nearly every material under nearly any conditions (4).

- **Mercedes Bionic Car:**

In looking to create a large volume, small wheel base car, the design was based on the boxfish (ostracion meleagris), a surprisingly aerodynamic fish given its box like shape. The chassis and structure of the car have been designed using a computer modeling method based upon how trees are able to grow in a way that minimizes stress concentrations (5).

The resulting material is allocated only to the places where it is most needed (6) as shown in Fig. (i-6).

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(1) Reflective road studs marketing the middle of the road
(2) Stokholm, M., "Bionics".
(3) Ge, et al., "Carbon nano Tube-Based Synthetic Gecko Tapes".
(4) Autumn, K., "How Gecko Toes Stick".
(5) Zari, M., "Biomimetic Approaches to Architectural Design for Increased Sustainability".
(6) Vincent, J., et al., "Biomimetics: Its Practice and Theory".

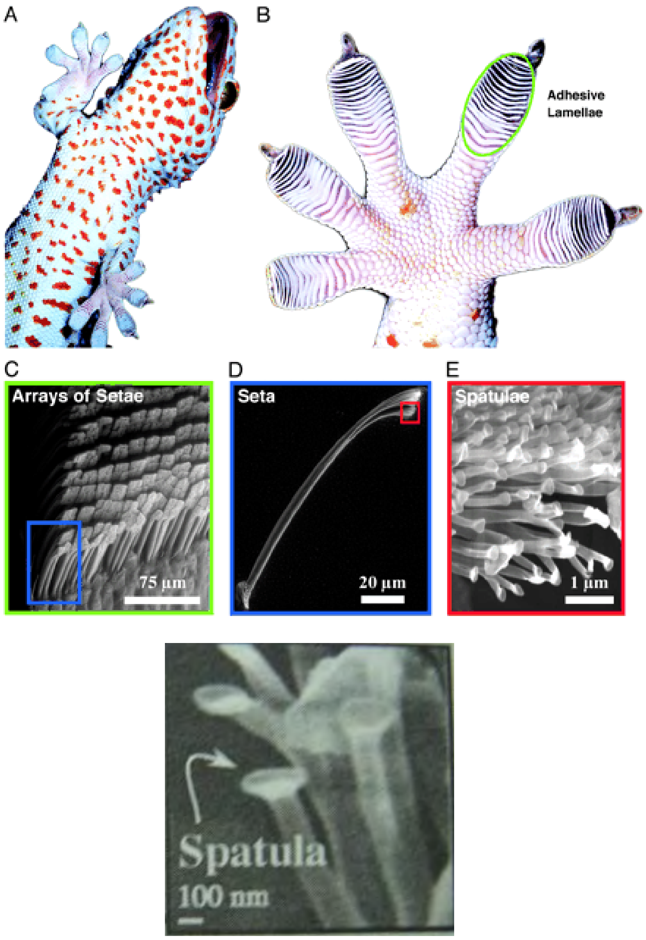

Figure (i-5): The Nano Structure of the Gecko Toe.
Up:(Hansen and Autumn, 2004), Down:(Forbes, 2006)

Figure (i-6): DaimlerChrysler Bionic Car Inspired by the Box Fish and Tree Growth Patterns.
(Zari, 2007)

III. Terminology

The concept of using ideas from nature to further technology has been given a number of names such as “Biomimesis”, “Biomimicry”, “Biomimetics”, “Bionics”, “Biognosis” or Bionical Creativity Engineering (1).

1. **Biomimesis :**

   From bios, meaning life, and mimesis, meaning to imitate "in Greek" (2).

2. **Biomimicry** :

   (From bio+mimicry, meaning to copy the action of).

   - mim·ic:

     To behave or operate in exactly the same way as something or someone else.

     For example, we say: The drug mimics the action of the body's own chemicals (3).

   - The name Biomimicry was coined by Janine Benyus at her book "Innovation inspired by nature", which was first published in 1997.

3. **Biomimetics**

   - mimet·ic:

     Copying the movements or appearance of someone or something else (3).

   - The name biomimetics was coined by Otto Schmitt in the 1950s. Otto Schmitt was a polymath, whose doctoral research was an attempt to produce a physical device that mimicked the electrical action of a nerve (4).

---

(1) www.bath.ac.uk
(2) Benyus, J., “Biomimicry: Innovation Inspired by Nature”.
(3) www.ldoceonline.com
(4) Vincent, J., et al., “Biomimetics: Its Practice and Theory".

The word made its first public appearance in Webster's Dictionary in 1974, accompanied by the following definition:
“The study of the formation, structure, or function of biologically produced substances and materials and biological mechanisms and processes (as photosynthesis) especially for the purpose of synthesizing similar products by artificial mechanisms which mimic natural ones (1). ”

4. **Bionics :**

- Possibly originating from the Greek word "βίον", pronounced "bion", meaning "unit of life" and the suffix -ic, meaning "like" or "in the manner of", hence "like life" (2).
- Some dictionaries explain the word as being formed from "biology" + "electronics" (2).
- In German, the word for bionics is “Bionik,” a portmanteau word comprising the words “Biologie” [biology] and “Technik” [technology] (3).
- The word 'bionic' was coined by Jack E. Steele of the US Air Force in 1958(1).

Biomimetics not Bionics:

Biomimicry or biomimetics is more preferred in technology world in efforts to avoid confusion between the medical term bionics

- In medicine, Bionics means the replacement or enhancement of organs or other body parts by mechanical versions. Bionic implants differ from mere prostheses by mimicking the original function very closely, or even surpassing it (2).

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(1) Vincent, J., et al., “Biomimetics: Its Practice and Theory", p. 471.
(2) www.bioengineer.in/2009/01/bionics/
(3) www.rhenotherm.com/glossar.0.html

Confused concepts:

The following definition can be found on line:

"Bionic architecture is a movement for the design and construction of expressive buildings whose layout and lines borrow from natural forms. The movement began to mature in the early 21st century, and thus in early designs research was stressed over practicality.

Bionic architecture sets itself in opposition to traditional rectangular layouts and design schemes by using curved forms and surfaces reminiscent of structures in biology and fractal mathematics. One of the tasks set themselves by the movement's early pioneers was the development of aesthetic and economic justifications for their approach to architecture (1)."

This definition deals with bionics from a superficial point of view, expressing lines and layouts, ignoring strategies and functions as a source of inspiration, and sustainability as a goal to reach.

IV. Inspiration in architecture:

Two fields of design inspired by nature in architecture can be detected:

- Construction:
    - Constructing crystal palace after the creation of water lily.
    - Constructing Roman Gatti factory after human's thighbone (2).

Figure (i- 7) Construction Inspired by Nature.
Left: Crystal palace inspired by water lily.
Down: column structure of Roman Gatti factory after human body's thighbone.
(Chiu and Chiou, 2009)

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(1) www.bionity.com/lexikon/e/Bionic_architecture/
(2) Chiu, W., and Chiou, S., "Discussion on Theories of Bionic Design".

- **Environmental design:**
  - Design an office building in Zimbabwe after termite mounds.
  - Producing external paint which lasts for 5 years after a self cleaning mechanism located in lotus flower.

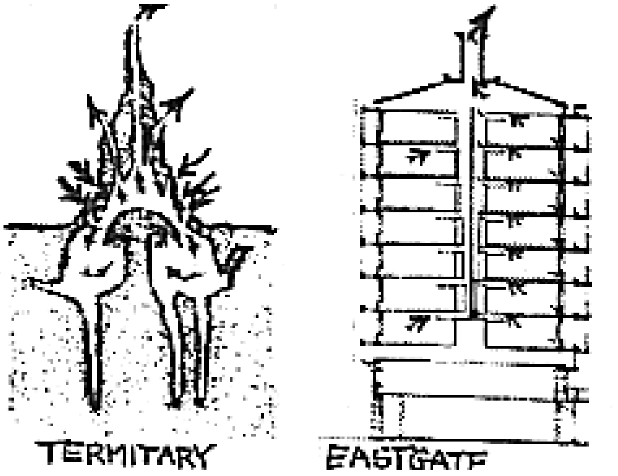

Figure (i-8) Eastgate Building after Termite Mound *(Zari, 2007)*

Figure (i-9) Lotusan Paint after Lotus Flower Self Cleaning mechanism. *(Yahya, 2006)*

This work is concerned with environmental topics rather than constructural ones.

V. Why biomimetics:

When designing a new product, the right qualities and properties can often be found in God creatures as they work for maximum achievement at minimum effort.

Benyus states that animals, plants, and microbes are the consummate engineers. They have found what *works,* what is *appropriate,* and most important, what *lasts* here on Earth (1).

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(1) Benyus, J., "Biomimicry: Innovation Inspired by Nature".

VI. Pioneers of the new discipline:

- **Janine Benyus**

Natural sciences writer, innovation consultant, and author of six books, including her latest "Biomimicry: Innovation Inspired by Nature” (1).

In this book she develops the basic thesis that human beings should consciously emulate nature's genius in their designs.

In 1998, Benyus (2) co-founded the Biomimicry Guild, the Innovation Consultancy, which helps innovators learn from and emulate natural models in order to design sustainable products and processes.

She is also President of the Biomimicry Institute, a non-profit organization whose mission is to naturalize biomimicry in the culture by promoting the transfer of ideas from biology to sustainable human systems design (3).

Figure (i-10):
Janine M. Benyus
(www.naturaledgeproject.net/BenyusTour06.aspx)

- **Julian Vincent**

Professor of Biomimetics. He was a biologist, but over the years he taught himself materials Science and engineering.

He set about developing methods for bridging the gaps between those disciplines .His search led to TRIZ, a problem-solving tool established in 1946 by a Russian engineer. He formed a small team to develop these ideas to underpin biomimetics (4).

Figure (i-11):
Julian Vincent
(www.bath.ac.uk/news/images/julian-vincent2.jpg)

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(1) Benyus, J., “Biomimicry: Innovation Inspired by Nature”.
(2) Janine has received several awards including the 2009 Champion of the Earth award in Science & Innovation from the United Nations Environmental Program.
(3) www.wikipedia.com
(4) www.cseng.org.uk

VII. The Goal:

This work aims at exploring the new discipline of biomimicry and also exploring its possibilities in the field of environmental architecture.

In this context, environmental architecture must be defined here.

Environmental architecture is a highly efficient building system, through which all the positive features of the external environment are employed, and all the negative features are controlled, in an integrated methodological way, in order to reach comfort conditions in the space, during time, with the least direct and indirect cost. This cost is measured with energy measuring units.

Many of the components of any of the environmental design problems are changing in time and position causing tens of contradictions between the features according to the goal that designers aim to fulfill by design. This leads to a bunch of scenarios of which a designer has to choose out, in a systematic way, the most efficient and appropriate scenario that fulfill his aim in the short and long term

VIII. The Objectives:

1. Presenting a definition of the new discipline, based upon viewing all the available definitions of the new term.
2. Presenting the main principles of natural designs, linked with the field of architecture.
3. Finding how environmental architecture can get use of biomimicry.
4. Presenting a comprehensive study of the biomimicry design methods.
5. Focusing on the BioTRIZ method, as one of the biomimicry design methods, and find out if its inventive principles could be interpreted to help architects find environmental solutions.

IX. Thesis Structure:

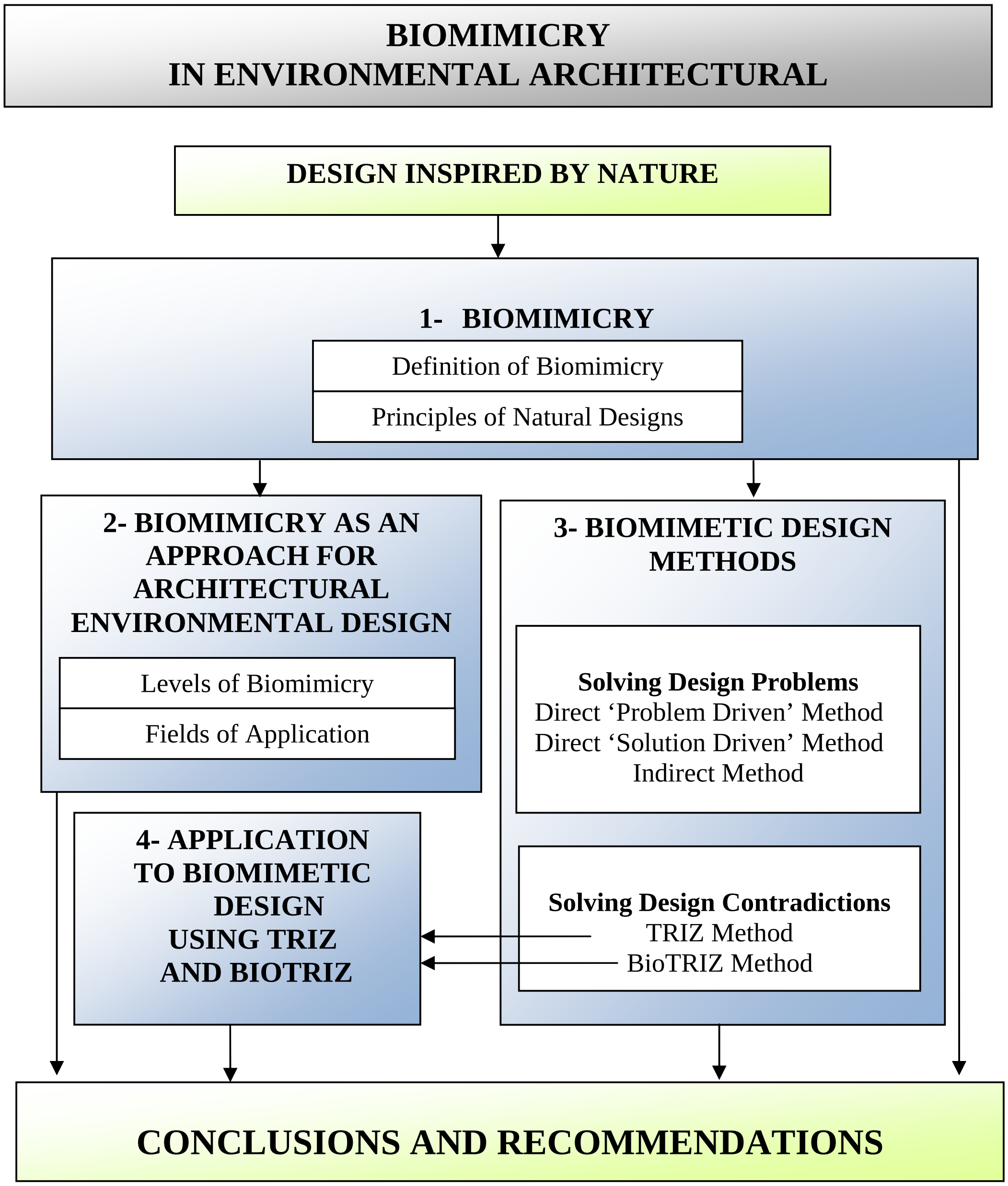

Figure (i-12) Thesis Structure

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(1) www.Biomimicryguild.com

Chapter 1

BIOMIMICRY

"We don't seek to imitate nature,
but rather to find the principles she uses".
..Buckminster Fuller.

Chapter 1

BIOMIMICRY

1.1. Definitions of Biomimicrv

1.2. Principles of Natural Designs

- 1.2.1. Running on sun and natural resources
- 1.2.2. Using only the needed resources
- 1.2.3. Fitting form to function efficiently
- 1.2.4. Recycling everything
- 1.2.5. cooperation and symbiosis
- 1.2.6. Developing diversity of possibilities
- 1.2.7. Requiring local expertise
- 1.2.8. Avoiding excesses and overbuilding
- 1.2.9. Tapping the power of limit
- 1.2.10. Network creation instead of linearity
- 1.2.11. Organizing fractally
- 1.2.12. Relying upon swarm intelligence

Chapter 1

BIOMIMICRY

Chapter One

Biomimicry

Biomimetics is defined as “The abstraction of good design from nature (1).” Good design means optimal design, as nature works for maximum achievement with minimum effort (2).

When God had created all these kinds of creatures in different environments-some of these creations are related and usefull to us, some of them are far away from human habitats and also far away from fulfilling any of human needs, some others are not even discovered yet, it seems that God aimed at offering us a wide range of strategies and processes that every creature adopts to live, in order to apply these stategies to enhance our life on earth.

Environmental Architecture is one of the most fields that have a lot to learn from nature, as Vincent states that architecture has much to learn from systems that when evolving with their environment display high levels of integration and functionality (2).

1.1. Definitions of “Biomimicry":

Several definitions of the discipline will be viewed here, followed by a brief commentary, where it is needed.

1-Biomimetics is an enabling discipline which looks towards nature for ideas that may be adapted and adopted for solving problems. It is: ‘Inspiration rather than Imitation (3).’

2-Major Jack Steele, who coined the term “Bionics” defined it as:

“The analysis of the ways in which living systems actually work and having discovered nature's tricks, embodying them in hardware (4).”

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(1) www.reading.ac.uk/biomimetics/biomimetics%20at%20Reading.pdf

(2) Moor, D., “Digital Design Methods”.

(3) www.extra.rdg.ac.uk/eng/BIONIS/

(4) Talabă, D., and Roche, T., “Product Engineering: Eco-Design, Technologies and Green Energy”.

- The term "tricks" is not scientific, and the word "hardware" does not express the wide scope that biomimicry really serves.

3-"Biomimicry is the art of consciously recapitulating the genius of 3.8 billion years of trial and error to improve everything we design (1)."

- The expression "the genius of 3.8" is more literary than scientific, and I don't agree with the idea of trial and error, because God does not need to "try"and his creation could never include an "Error", but the expression "improve every thing we design" expresses the wide scope that biomimicry really serves, contrary to the previous definition.

4-"Biomimicry is a new discipline that studies nature's best ideas and then imitates these designs and processes to solve human problems (2)."

- Nature as God creation does not include "bad", "good" or "better".

5- "Biomimicry is the science of taking inspiration from nature, its models, systems, processes and elements to solve design problems sustainably" (3).

6-"Biomimicry is an innovation method that seeks sustainable solutions by emulating nature's time-tested patterns and strategies, to create products, processes, and policies that are well-adapted to life on earth" (4).

- The term "Time tested pattern" depends on a concept, that the extinct creatures are those who could not adapt to their environments.

  Benyus states that after 3.8 years of research and development, failures are fossils, and what surrounds us is the secret to survival (4). The concept may be reasonable, and the definition may tell us to stick to creatures that are "here" in our environment and "now" in our age.

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(1) www.sustainabledesignupdate.com
(2) www.biomimicryinstitute.org
(3) www.sustainabledesignupdate.com
(4) Benyus, J., "Biomimicry: Innovation Inspired by Nature".

7- The Concise Columbia encyclopedias define bionics as follows:
"The study of living systems with the intention of applying their principles to the design of engineering systems (1)."

8- Bionics is the science of studying the basic principles of nature, and the application of these principles and process for finding solutions for the problems that humanity encounters (2).

9- Biomimicry is an interdisciplinary field within biology and technology which covers systematic studies of functions, relations, structures, and processes in biological systems and the transformation of these to the solutions of primary technical and technological problems (3).

After examining all the above, the definition that can be adopted will be:
"Biomimicry is the study of forms, structures and mechanisms of natural living organisms to perform their functions."

---

(1) Podborschi, V., "Study of Natural Forms-The Source of Inspiration in the Product Design”.
(2) Talabă, D., and Roche, T., “Product Engineering: Eco-Design, Technologies and Green Energy”.
(3) Stokholm, M., “Bionics”.

1.2. Principles of Natural Design

"We do not seek to imitate nature, but rather to find the principles she uses." The words belong to Buckminster Fuller (1).

According to Fuller's saying, we don't seek to copy forms that we find in nature regardless the function achieved by these forms, or even to copy functional processes regardless the environments where these processes took place.

Successful biomimicry relies on conscious mimicry to a certain natural strategy that is mimicked in a similar-if not the same-environment, to achieve the same function using the minimum effort.

Conscious analysis to the general principles of natural designs could help us design better environmental-friendly architectural solutions.

The following list of principles contains nine principles that were stated by Janine Benyus the author of "Biomimicry: Innovation inspired by nature", but in the words of Onno Koelman (2) that were found more simplified. The last three principals were not stated by Janine, but by other resources as follows:

Natural designs:

1. Run on the sun and other 'natural sources' of energy.
2. Use only the energy and resources that it needs.
3. Fit form to function efficiently.
4. Recycle everything.
5. Reward cooperation and make symbiotic relationships work.
6. Develop diversity of possibilities.
7. Adjust to the Here and Now.
8. Avoid excesses and "overbuilding".
9. Tap the power of limits.

---

(1) Koelman, O., "Biomimetic Buildings: Understanding & Applying the Lessons of Nature".
(2) Koelman, O., "The Biomimicry Way".

1. Depend on network creation instead of linearity (1).
2. Depend on organizing fractally.
3. Rely upon swarm intelligence (2).

Each principle will be discussed, and how it is found in nature, and weather it has already applied in human designs.

1.2.1. Natural Designs Run on Sun and Other „Natural Sources' of Energy:

This principle is read in some sources:" Nature runs on sunlight" (3), and also:"Direct and indirect use of solar energy". But the main title is preferable as it includes other natural sources.

God has created living things in a way that they are able to take the most benefit of the natural sources, especially solar power.

In the plant world, Daffodils gives us a model. The daffodil has an inter-seasonal store; the daffodil famously stores energy in its bulb in summer – to utilize in the winter to get a head start on growth (4).

Since the daffodil runs on sunlight, it has managed to find a way to keep the energy it needs, to use it in a different season.

Keefe states that Bio-mimetic architecture will be dynamic, with a complex way of collecting, storing and utilizing energy, responding to climatic rhythms – minute-by minute, diurnal, and seasonal (4).

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(1) Stokholm, M., "Bionics".
(2) Faludi, J., "Biomimicry for Green Design (A How to)".
(3) Benyus, J., "Biomimicry: Innovation Inspired by Nature".
(4) Keefe, G., "Daffodil and Polar Bear: Towards a Biomimetic Architecture".

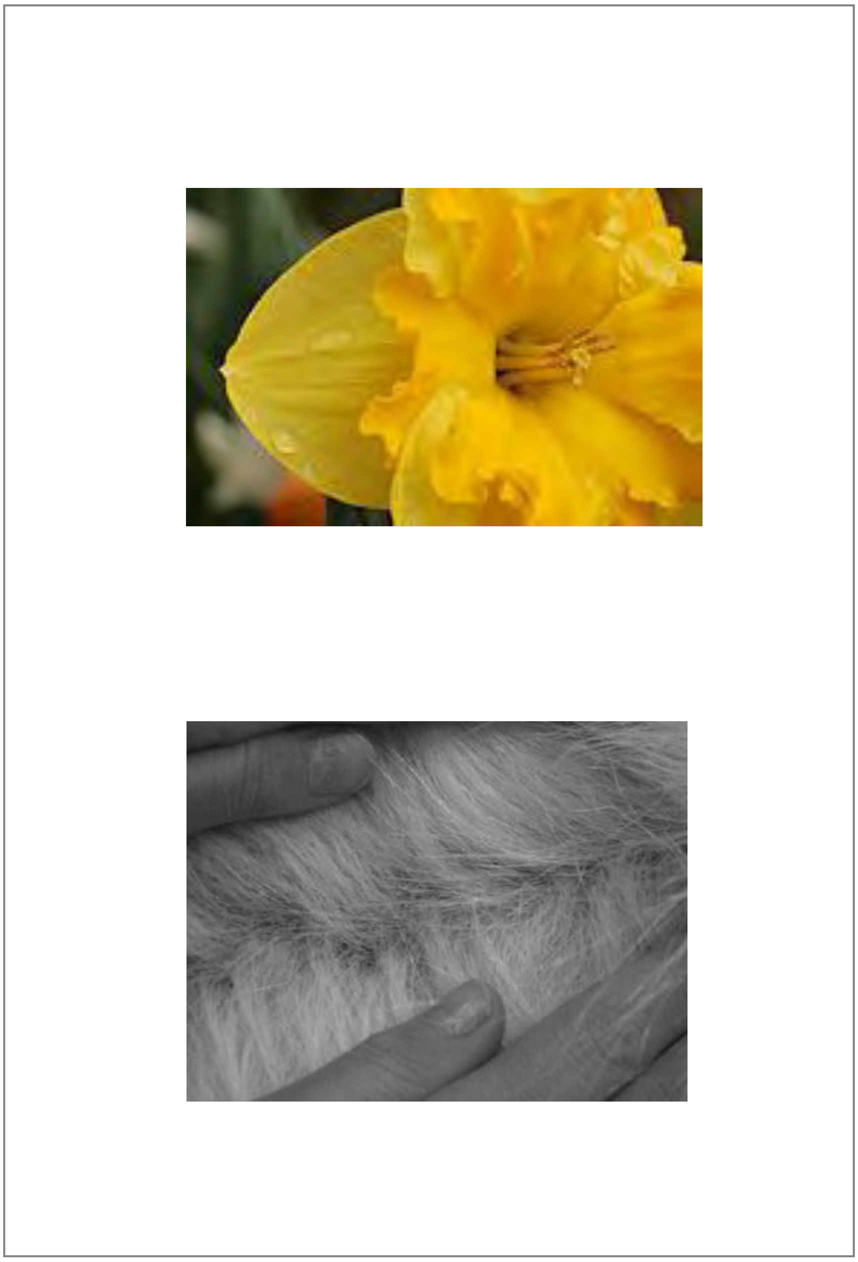

Figure (1-1): Plants and Animals Relying on Sunlight.
Up: Daffodil. (Day light and architecture, 2006)
Down: The black Skin under the Polar Bear's Fur. (Bhushan, 2009a)

Polar bear is also an interesting example from the world of animals. The skin of the polar bear is black, and thus good at absorbing energy (1).

When the bear raises his bristles, sun light penetrates to the black skin. The energy absorbed from the sun allows the bear to function without a highly isolative fat layer that would restrict its movement (2).

Like plants and animals have managed to get use of solar radiation, our buildings could have solar panels, systems for collecting groundwater like roots, systems that take rain and store it and/or systems that drink fog like Namibian beetle. Those systems allow the building to be self-sufficient energy-wise.

CH2 building designed by Mike Pearce is making benefit of both the solar and wind power, it is shown in Fig. (1-2). The building consumes 85 percent less electricity, 87 percent less gas and 72 percent less potable water.

1.2.2. Natural Designs Use Only the Energy and Resources That It Needs:

This principle is linked with other principles that are considered giving the same result:

- “Limited life time instead of unnecessary durability”
- “Multi functional instead of mono functional”
- “Optimize the system rather than maximizing components ”or in another word:
- “Integration instead of additional construction”

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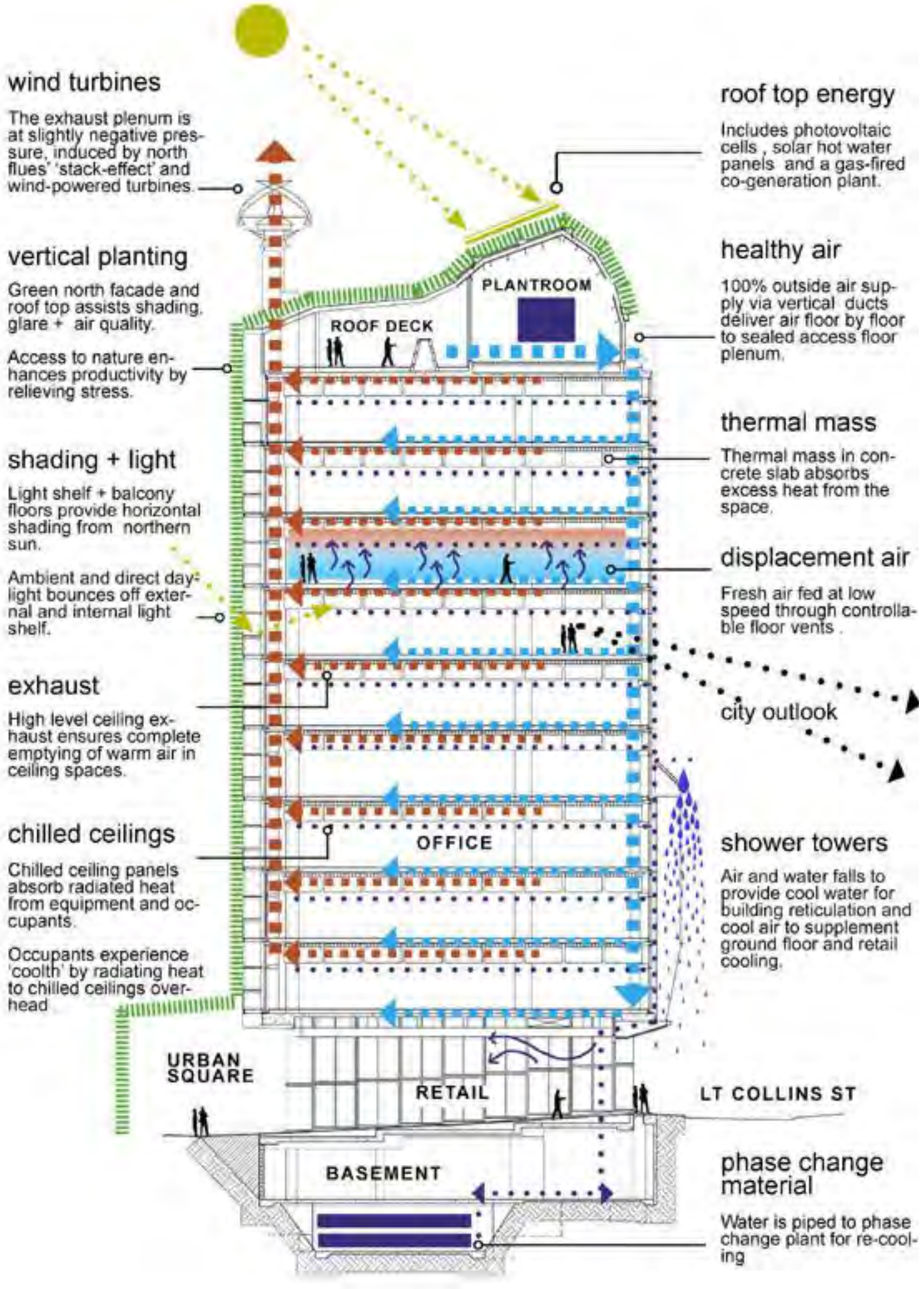
(1) Stokholm, M., “Bionics”.

(2) Keefe states that the bear’s fur is made up of highly insulating, translucent hollow fibers that act like fiber optics transmitting infra-red light from the surface to the skin of the black skin.
(Keefe, G., "Daffodil and Polar bear: Towards a Biomimetic architecture")
While Julian Vincent states that it appears impossible for the hairs to act as light guides since they are largely hollow, and the air spaces will reflect and disperse radiation rather than transmitting it.
(Vincent, J., Biomimetics: Its practice and theory).

In1988, Daniel W. Koon, a physicist at St. Lawrence University in Canton, NY, and graduate assistant, Reid Hutchins, proved that the black skin absorbs very little ultraviolet light. Instead, Koon believes keratin, a basic component of the hair, absorbs the ultraviolet light.
(http://www.polarbearsinternational.org/polar-bears/bear-essentials-polar-style/characteristics/fur-and-skin)



wind turbines

The exhaust plenum is at slightly negative pressure, induced by north flues' 'stack-effect' and wind-powered turbines.

vertical planting

Green north facade and roof top assists shading, glare + air quality.

Access to nature enhances productivity by relieving stress.

shading + light

Light shelf + balcony floors provide horizontal shading from northern sun.

Ambient and direct daylight bounces off external and internal light shelf.

exhaust

High level ceiling exhaust ensures complete emptying of warm air in ceiling spaces.

chilled ceilings

Chilled ceiling panels absorb radiated heat from equipment and occupants.

Occupants experience 'coolth' by radiating heat to chilled ceilings overhead

roof top energy

Includes photovoltaic cells , solar hot water panels and a gas-fired co-generation plant.

healthy air

100% outside air supply via vertical ducts deliver air floor by floor to sealed access floor plenum.

thermal mass

Thermal mass in concrete slab absorbs excess heat from the space.

displacement air

Fresh air fed at low speed through controllable floor vents .

city outlook

shower towers

Air and water falls to provide cool water for building reticulation and cool air to supplement ground floor and retail cooling.

phase change material

Water is piped to phase change plant for re-cooling

Figure (1-2) CH2 Building Runs on Sun and Wind
(http://arcilook.com/wp-content/uploads/bio-northsouth-10-12-03.jpg)

- **"Limited life time instead of unnecessary durability":**

Karolides states that before building a building, few questions should be asked (1):

1-Is it necessary?

One of the key ways of reducing resource consumption and cost is to evaluate first whether a new building needs to be built. Renovating an existing building can save money, time, and resources

2-What exactly is the needed volume?

If a new building is required, it should be sized only as large as it really needs to be. Smaller buildings require fewer materials, less land, and less operational energy.

The third question comes from the sub-principle:" Limited life time instead of unnecessary durability":

3- What exactly is the needed lifetime?

The modern direction to flexibility has risen the idea that we don't really need buildings that lasts for centuries, as people changes, so does their needs and hence the properties of the buildings that respond to these needs.

These three questions strongly reflect the two principles:"Using only the needed resources" and "Limited life time instead of unnecessary durability".

National Space Centre Exhibition and Research Complex in England is an example of reducing resources and materials. The building is designed by Grimshaw Architects. Grimshaw proposed to use the existing 100-year-old stormwater tank by building the project into its footprint. The tank provided a reuseable base and eliminates the need to pour new concrete and waste energy on site modifications. The old water tank and the new building are shown in Fig. (1-3).

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(1) Karolides, A., "An Introduction to Green Building".

Figure (1-3) National Space Centre Exhibition and Research Complex.
Left: Old storm water tank. Photo by Rona Burnett
Right: The 40m high transparent tower. Photo by Philip Jordan.
(www.caa.uidaho.edu)

- **“Multi functional instead of mono functional”**

This sub-principle should be taken into consideration when designing the building elements, as it is widely applied in nature. The skin of the whale and the cuticle of plants are examples.

- **Multifunctionality of the whale body cover:**

The whale body cover shown in figure (1-4) exemplifies this principle. The figure shows the variable blubber depth comparing to the length of the whale which is 155 cm, taking into consideration that it varies with locality, time of year and size of wale [1].

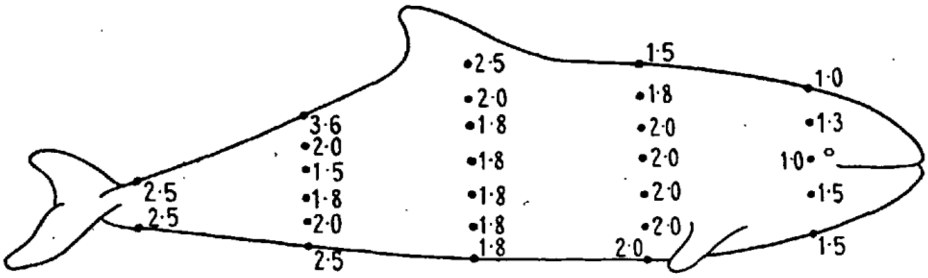

Figure (1-4) Depth of Blubber in Centimeters.
(Parry, D., 1949)

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[1] Parry, D., “The Structure of Whale Blubber, and a Discussion of its Thermal Properties”.

According to Yahya, the cover of this creature offers it:

1-The ability to float: The layer of fat covers the bodies of dolphins and whales, serving as a natural flotation mechanism that allows whales to rise to the surface to breathe.

2-Insulation: The fat layer protects these warm-blooded mammals from the cold waters of the ocean depths.

3-Energy: During a whale's nonfeeding migration of thousands of kilometers, when it is unable to find sufficient food, it obtains the needed energy from this fat in its body.

4-High speed: Whale blubber is a very flexible rubberlike material. Every time it beats its tail in the water, the elastic recoil of blubber is compressed and stretched. This provides the whale with extra speed and allows a 20% energy saving on long journeys (1).

- **Multifunctionality of cuticles of plants:**

The cuticles of plants provide a multifunctional interface between the plants and their environments. The cuticle with its associated waxes is a protective layer that minimizes water loss by transpiration and provides several functions such as hydrophobicity, light reflection and absorbtion of harmful radiation (2).

The same principle can be applied in architecture. Like the whale body cover and the cuticle of plants offer them many functions, the skin of buildings should also perform multi functions like shading, ventilation, lighting and isolation.

Another interested idea to reduce the replacement cost. A new carpet was developed that mimics the random patterns of the forest floor (3).

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(1) Yahya, H., "Biomimetics: Technology Imitates Nature".
(2) Koch, K. et al., "Self-Healing of Voids in the Wax Coating on Plant Surfaces".
(3) Watson, S., “Learning from Nature”.

Koelman states that these carpet tiles that copy the ever-changing pattern of the forest floor, reduces excessive cost in repair and installation; because when one high-traffic area tile wears out, a new one will be slipped in, without a noticeable pattern (1).

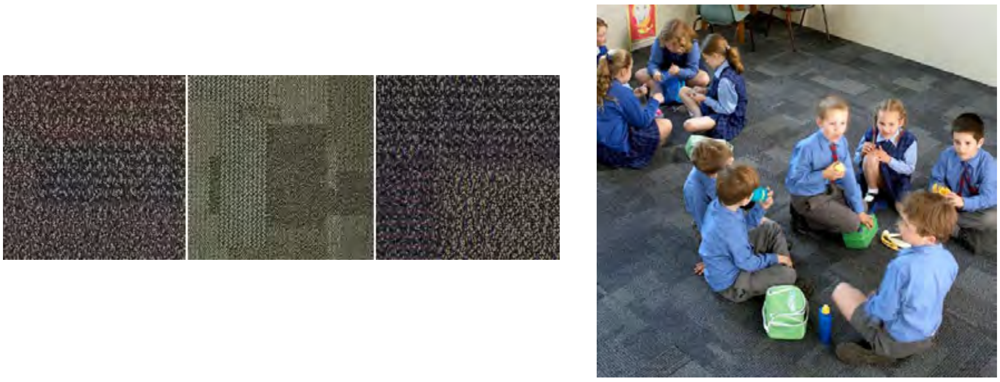

Figure (1-5) Economic Carpet Tiles Inspired by Forest Floor.
(www.design boom.com)

1.2.3. Natural Designs Fit Form to Function Efficiently:

The Namibian desert beetle lives in a desert with negligible rainfall. It is able to capture moisture from the swift moving fog that moves over the desert by tilting its body into the wind. Droplets form on the alternating hydrophilic (2) – hydrophobic (3) rough surface of the beetle's back and wings and roll down into its mouth (4) as shown in Fig (1-6).

Figure (1-6)
Namibian Desert Beetle
(Photo by Melisa Beveridge. www.science-art.com/search_main.asp)

The beetle back was formed according to the function required; its Nano-structure shows the hydrophilic high surface that attract water droplets, and hydrophobic low surface that is coated with a layer of wax.

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(1) Koelman, O., "Building the Future of Buildings".
(2) Hydrophilic surfaces: surfaces having strong attraction or ability to absorb water.
(3) Hydrophobic Surfaces: Surfaces which are water-repellent; tending to repel and not absorb water.
(4) Zari, M., "Biomimetic Approaches to Architectural Design for Increased Sustainability".

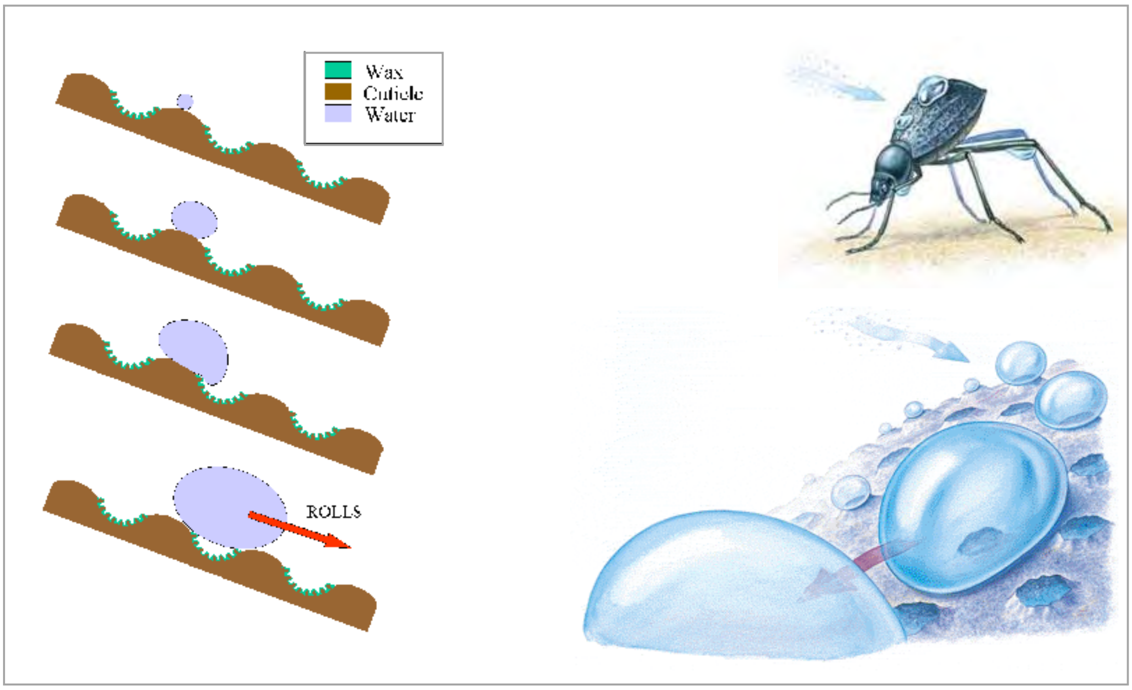

Figure (1-7) The Alternating Hydrophobic-Hydrophilic Surface of the Namibian Beetle's Back
(http://biomechanics.bio.uci.edu/_html/nh_biomech/namib/beetle.htm)

This alternation makes the water droplets form on the hydrophobic high surfaces until it reaches a certain volume then it rolls down over them into the beetle mouth (1) as shown in Fig (1-7).

1.2.4. Natural Designs Recycle Everything:

Nature works in cycles, perfectly closed loops, so that nothing is wasted. The simplest example is the hydrologic cycle.

The hydrologic cycle is a never-ending global process of water circulation from clouds to land, to the ocean, and back to the clouds (2), all water molecules eventually cycle through the hydrologic cycle.

Nowadays, this concept is very important, not only because wastes could be new recourses, but also because throwing them to the landfills costs a lot.

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(1) The building that mimics the beetle's skin will be mentioned at pp. 64-65.
(2) http://science.nasa.gov/earth-science/oceanography/ocean-earth-system/ocean-water-cycle/

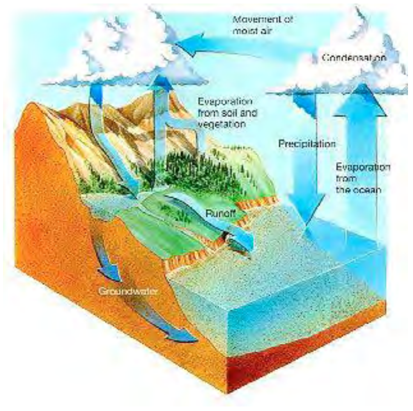

Figure (1-8) The Hydrologic Cycle
(www.ort.edu.uy)

Figure (1-9) Tower of Tomorrow
(*www.building.co.uk)*

"Cradle to Cradle" is a title of a book, written by the architect William McDonough (1); it is the opposite of the common phrase "Cradle to grave". It expresses the idea that buildings should be built by totally recycled materials.

McDonough has designed the tower of tomorrow in which he has applied his ideas.

In this building, the waste water from sinks and bathtubs would be recycled and used for irrigation in the gardens; the waste water from gardens could further be reused in toilets; all products from building materials to furnishings could be recycled or return safely to the earth in true cradle to cradle fashion (2).

The same concept is sometimes read under the title:

- **"Waste = food"** (3)

However, "Waste = food" is highly related to the next principle:"Nature rewards cooperation and makes symbiotic relationships work.

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(1)William McDonough built the first solar-powered house in Ireland in 1977, received the first and only Presidential Award for Sustainable Development for an individual in 1996 and was entitled "Hero of the Planet" in 1999 by the Time magazine.

(2) www.inhabitat.com/2008/01/02/the-building-of-tomorrow-that-works-like-a-tree

(3) Faludi, J., "Biomimicry for Green Design (A How to)".

1.2.5. Natural Designs Reward Cooperation and Makes Symbiotic Relationships Work:

Koelman states that building can and should be a net contributor to its surroundings. The typical waste streams and garbage that come from buildings (including wastewater and food scraps) could be fed into Living Machines™ (1) and recycled, feeding the fish that swims in the pond under the waterfall in the naturally- illuminated and ventilated lobby atrium (2).

Koelman highlights the positive suggested relation between man and a small fish that is invited to be an important part of the design. Wastes go to feed the fish, and the fish participates in the process of purifying used water and hence presents a new clean stream of water that eliminates costs and saves resources.

In the "Eco-industrial Park", in Denmark, shown in Fig. (1-10), a cluster of industries and businesses are sharing their wastes, mimicking cooperation and symbiotic relationships found in nature, where flows of waste from one process become food for another.

The participants are:

- Coal-fired power plant
- Refinery
- Pharmaceutical and industrial enzyme plant
- Wallboard company
- Town's heating facility

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(1) Living Machines™ are systems used to purify water by mimicking the way ponds and marches work in nature. They will be viewed lately at p. 47.

(2) Koelman, O., "Building the Future of Buildings".

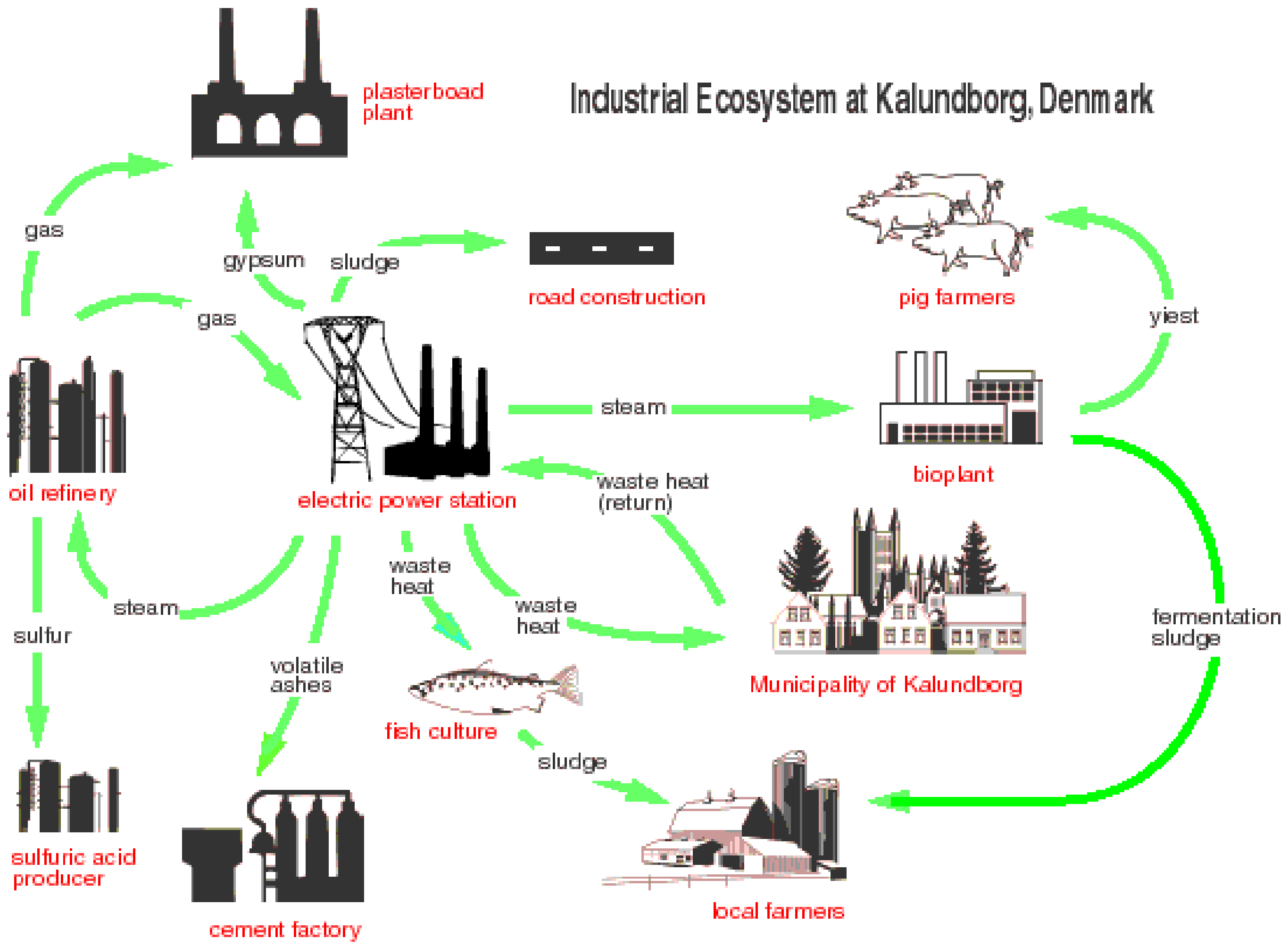

Figure (1-10) Symbiotic Relationships in the Industrial Ecosystem at Kalundborg
(http://newcity.ca/Pages/industrial_ecology.html)

The five different activities exchange a variety of resources, like steam, hot water, and materials such as synthetic gypsum, sulfuric acid, and biotech sludge, in a manner that is beneficial to everyone involved.

As a result to this waste sharing process, companies save landfill costs and generate revenues from previously unusable by-products.

Figure (1-11) The Industrial Ecosystem at Kalundborg. View from Around the Asnaes Power Station
(www.kythuatvatlieu.org/definition/categories.html?view=mediawiki&article =File%3AView_from_Asnaes_power_station_Kalundborg_Denmark.jpg)

1.2.6. Natural Designs Develop Diversity of Possibilities:

In her book, Janine Benyus called this principle:

- **“Nature banks on diversity”** (1).

Other resources name it:

- **” Diversity to fill every niche”** (2).

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(1) Benyus, J., “Biomimicry: Innovation Inspired by Nature”
(2) Faludi, J., "Biomimicry for Green Design (A How to)”.

It includes the idea of using all energies available instead of relying only on one solution, using photovoltaic panels parallel to wind turbines in addition to hydrogen fuel; all in one building is an example.

This could be clearly seen in The 2211 West 4th building in Vancouver, B.C., where a combination of energy strategies are used, including closed-loop, ground source heat pump uses "heat transfer" fluid to take heat from the ground and oil-drilling crews drilled 46 wells, 90 m deep, work side by side with the electric baseboards to heat the building.
Condominiums are heated with efficient gas fireplaces, electric baseboards and radiant floors (1).

Another idea about diversity, linked with "Waste = food" principle appears: "Smart manufacturers close their own resource loops; smart entrepreneurs **close other people's** loops (2)."

Fauldi suggests searching for wastes that will be inputs for industries, even if the search had to be far away from the place of industries.

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(1) Green Buildings in British Columbia Case Study Series.
(2) Faludi, J., "Biomimicry for Green Design (A How to)".

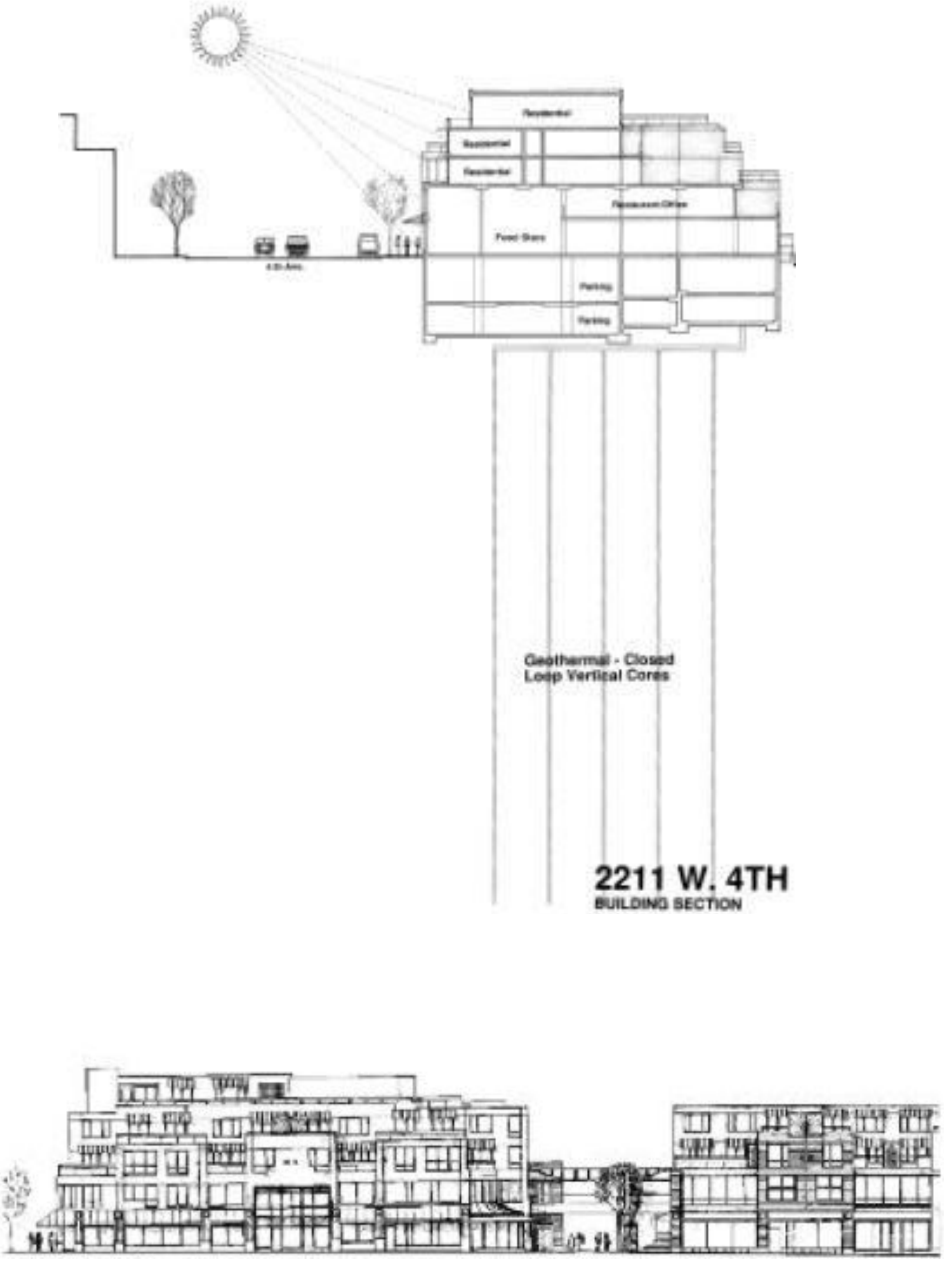

Figure (1-12) 2211 West 4th Building, Vancouver, B.C
(Green Buildings in British Columbia Case Study Series. at: www.greenbuildingsbc.com/Portals/0/docs/case_studies/2211_West.pdf)

1.2.7. Natural Designs Adjust to the Here and Now:

This principle has an alternative title:
"Natural Designs Require Local Expertise"

In natural designs, there is no solution that fits for all locations, and so should human designs be, all human solutions should be local, if architects deeply believe in this concept, comfortable interiors will be accomplished and healthy environment will still be saved.

"In his book Theories of Ecological Perception, JJ Gibson states that the environment and the animal are inseparable - the existence of one implies the existence of the other, and thus a perfect description of one, will imply an exact solution of the other (1)*."*

For example, an existence of a plant like a Savannah, would suggest the exsistance of animals like antelope and lion. In the same way, by defining the site of the building accurately, climatically and otherwise, this should suggest possible solutions that could be appropriate.

The idea is worth consideration, every environment has its own animals, that are created to be adapted to its conditions; and also its own plants that are not only adapted to its conditions, but also offers more suitable conditions to the animals living in this environment.

"Trees and animals have, over time, developed customized attributes to help them thrive in these niches. More or fewer leaves, deeper roots, water storing strategies etc., all vary from place to place (2)*."*

Architects begin to realize that their designs can reach standard comfort levels and efficiencies if they take into account local weather patterns and design accordingly.

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(1) Keefe, G., "Daffodil and Polar Bear: Towards a Biomimetic Architecture".
(2) Koelman, O., "The Biomimicry Way".

Here, climate is considered the most important factor that architects should respect, to produce architecture that offers comfortable interiors without harming our environments. In this context Keefe states that Biomimetic architecture will be ordered in a way that responds to the climatic demands of the site and the spatial and environmental needs of the brief (1).

The Eastgate office building design was a reflect to the local climate in Zimbabwe where the heat is swinging widely between day and night, the design mimicked the strategy found in termite mounds to accomplish the same function. Termite mounds in South Africa stay at 87 degrees all year around, all day long, in desert conditions (2).

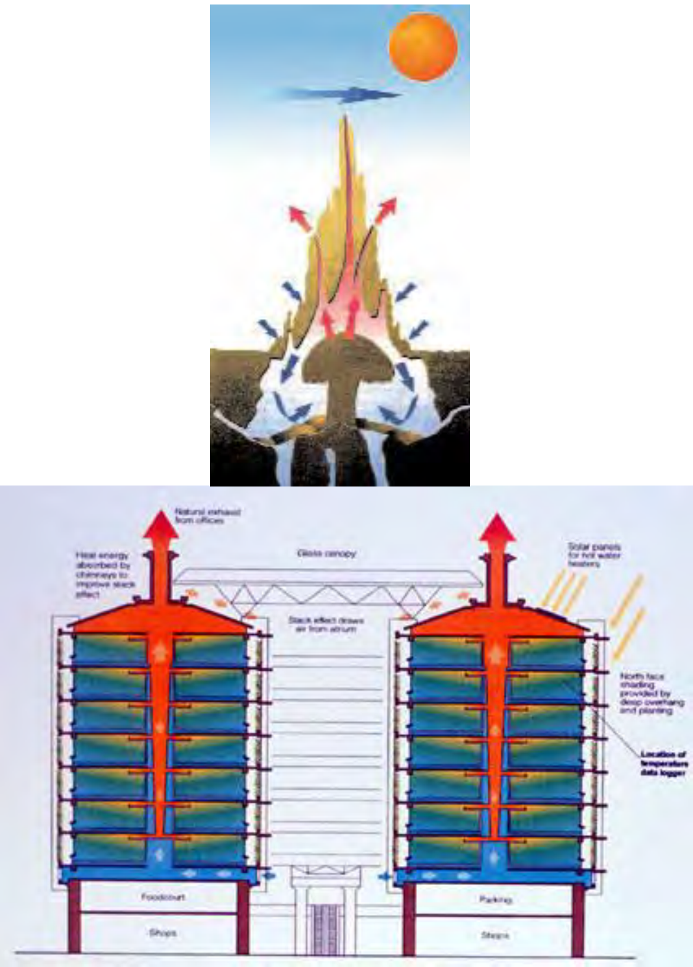

Figure (1-13) Eastgate Office Building after Termite Mound
(Johnston, 2001)

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(1) Keefe, G., "Daffodil and Polar Bear: Towards a Biomimetic Architecture".
(2) Oakey, D., “Biomimicry/ BioDesign”.

The Strategies that were found in termite mound and mimicked in the building can be viewed as follows:

1. The thermal mass of the mound has sufficient heat capacity to buffer the internal environment from heat gain during the day with cold accumulated over the night.
2. Narrowing shafts rising through the mound channel and accelerate the release of warm internal air out vents at the mounds' top.
3. Openings at the base of the mound allow cooler, denser air to flow in replacing warmer air as it rises. Fig (1-13).

Even the pattern, used in the outer envelope of the building and shown in Fig. (1-15) has its roots in the history of Zimbabwe (0). This has nothing to do with biomimicry in our context, but it shows great respect to the principle: "adjust to the here and now."

Figure (1-14) Great Ruins of Zimbabwe
(www.places.co.za)

Figure (1-15) Eastgate Façade Patterns Resembles the Great Ruins of Zimbabwe
(Johnston, 2001)

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(0) Johnston, L., "Ant Hill".

1.2.8. Natural Designs Avoid Excesses and "Overbuilding":

Building only what is needed reduces energy, materials and resources, and this leads to the second principle:" Nature uses only the energy and resources that it needs".

Human bone may be the most interesting lesson in this regard. Construction inspired by nature is not the issue of this work, but it will be viewed here because of its relation to material saving.

The latticework, copied from bones, has become one of the basic elements employed in construction techniques today. It requires fewer materials, and makes for a building framework that's both strong and flexible (1).

In the early 1850s, an anatomist Hermann von Meyer found that the part of the thigh bone that inserts into the hip joint, consists not of one single piece, but contains an orderly latticework of tiny ridges of bone known as trabeculae. The trabeculae were a series of studs and braces effectively arranged along the lines of force generated when standing.

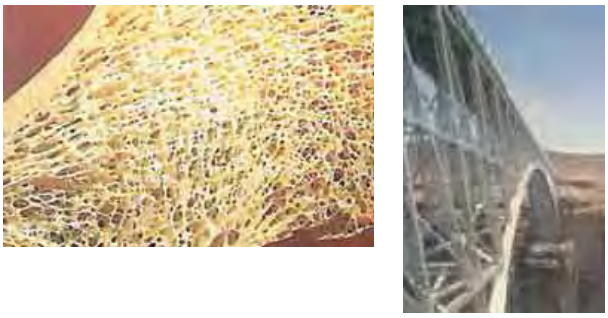

Figure (1-16) Lattice Work in Human Bone Inspired Many Architectural Works
(Yahya, 2006)

In 1866, the Swiss engineer Karl Cullmann realized that the bone's structure was designed to reduce the effects of weight load and pressure; he translated these findings into an applicable theory and the model led to the design of Eiffel Tower (2).

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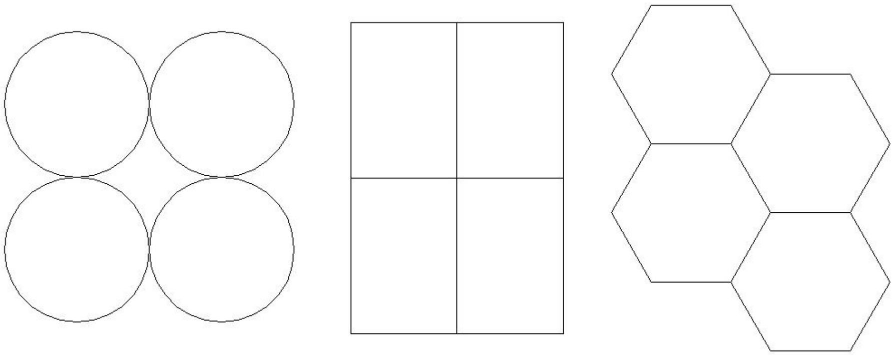
(1) Yahya, H., "Biomimetics: Technology Imitates Nature".
(2) Will be mentioned and illustrated at pp. 60-61.

Instead of using a block of expensive material, the used material can be concentrated in limited paths where the same load can be borne.

The same concept of using material in paths where loads are being transmitted have also led to the modern designs of dancing buildings (1).

The reason why the honeycomb takes its hexagon shape that this shape offers the bees the maximum storage space, with minimum material used (2). There is no waste area between the cells outline. And the material used to build a hexagon has found to be less than that used to build a rectangle with the same internal area.



Same storage area for three different shapes
Area ≈ 23.4cm

The circle uses minimal materials to build one cell, Circumference = 17.1cm, but it has many wasted area between the cells.

The rectangle has no wasted area but it requires more material to be built. Paramiter ≈ 19.7 cm.

The hexagon offers maximum storage space with less material used to be built
Paramiter ≈ 18 cm.

Figure (1-17) Honeycombs Hexagonal Shape
Up: Hexagon Compared to Rectangle and Circle. (By Researcher)
Down: The Honeycombs.
(www.gpscellphonetrackingtips.com/wp-content/uploads/2009/04/beehive.jpg)

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(1) Will be viewed at p. 61.
(2) Yahya, H., "Architects in Nature", Documentary video film.

1.2.9. Natural Designs Tab the Power of Limits:

A great number of organisms encounter the same environmental conditions that humans do and need to solve similar issues that humans face; these organisms tend to operate within environmental carrying capacity of a specific place and within limits of energy and material availability (1).

Janine states that humans regard limits as a universal dare, something to be overcome so they can continue their expansion. Other creatures take their limits more seriously, knowing they must function within a tight range of life-friendly temperatures, harvest within the carrying capacity of the land, and maintain an energy balance that cannot be borrowed against (2).

Ignoring limits may result in resources depletion, damaged environment and poor quality of life.

That's why this principle reflects another one, that says:

- "Don't foul your nest."

When God creates a tree in a forest, the tree doesn't grow up and bulldoze everything out of its path, nor does it have a larger footprint (i.e. resource drain) that it can sustain with its built-in root structure.

Learning from trees, when a designer sets a new building in an existing urban community, he should be sensitive to existing buildings, and design accordingly, and in case of a green field, he should design around existing landscapes and trees.

The more our architecture respects its surroundings the more likely it could be "conductive to life",(3) an architecture with which you can conduct pure and healthy life factors such as healthy soil, air and water to the coming generations.

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(1) Zari, M., "Biomimetic Approaches to Architectural Design for Increased Sustainability".
(2) Benyus, J., "Biomimicry: Innovation Inspired by Nature", p. 7.
(3) Conductive to life: is an expression of Janine Benyus.

The principle "Don't foul your nest" is also linked with the principle:

- "Nature recycles everything."

As polluting soil with landfills of construction waste is an example of fouling our nest.

1.2.10. Natural Designs Depend upon Network Creation Instead of Linearity:

Faludi states that we should design networks instead of pyramids.

The nodes should create the overall structure by their interrelations, because this method is more robust and flexible than a system with an overarching plan that must have certain nodes in certain places (1).

Figure (1-18) Network Creation in Radiolaria and Fuller's Dome
(Yahya 2006)

The Radiolaria, which is shown in Fig. (1-18), and the Geodesic dome of Buckminster Fuller exemplify the network creation.

1.2.11. Natural Designs Depend upon Organizing Fractally:

A fractal is an image that can be divided into parts; each of these parts will be similar to the original object (2). Fig. (1-19) illustrates the concept.

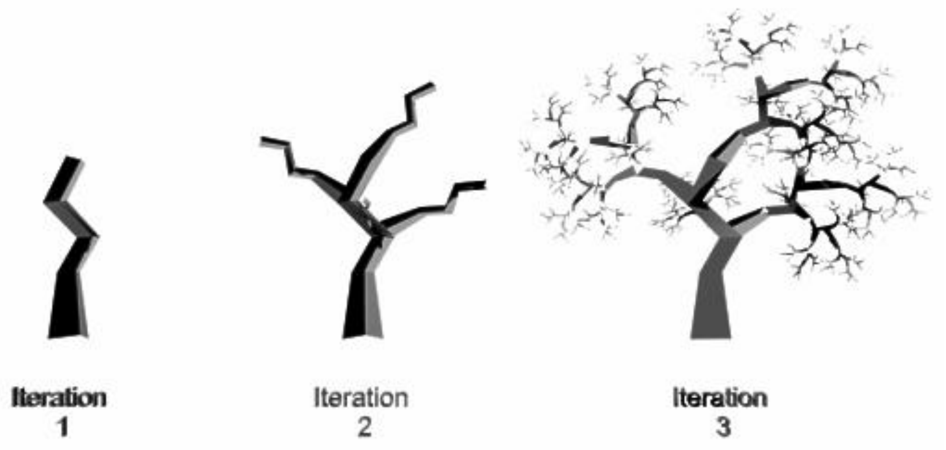

Figure (1-19) Iterations in the Fractal Image.
(Harris, 2007)

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(1) Faludi, J., "Biomimicry for Green Design (A How to)".
(2) http://cnx.org/content/m13371/latest/

A structure is self-similar if it has undergone a transformation whereby the dimensions of the structure were all modified by the same scaling factor. (1)

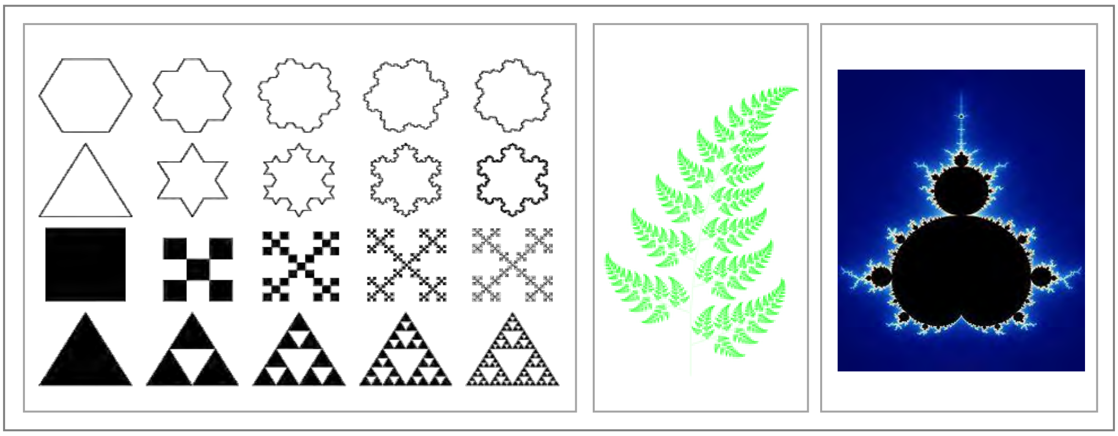

Figure (1-20) Fractals
Left "line by line": Gosper island, Koch snowflake, Box Fractal, Sierpiński triangle
(http://mathworld.wolfram.com/Fractal.html)
Middle: Barnsley's fern
(http://upload.wikimedia.org/wikipedia/commons/6/69/Bransleys_fern.png)
Right: Mandelbrot set (*http://en.wikipedia.org/wiki/Mandelbrot_set)*

Fractals in architecture:

Fractals in architecture can be divided into two levels, the scale of a single building and the scale of an urban growth (2).

The Building Level:

Fractal design could be applied in the layout design, in the elements of the facades and even in the elements of the interior space.

In the cathedral of Anagni I Italy which was built around 1104 there is a floor adorned with mosaics in the form of Sierpinski gasket (2) as shown in Fig. (1-21). Also the design of old Indian temples that is shown in Fig. (1-22) illustrates the fractal concept (3).

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(1) Novak, N., "Emergent Nature: Patterns, Growth and Scaling in the Sciences".
(2) SALA, N., "Fractal Models in Architecture: A Case Study".
(3) Joye, Y., "A Tentative Argument for the Inclusion of Nature-Based Forms in Architecture".

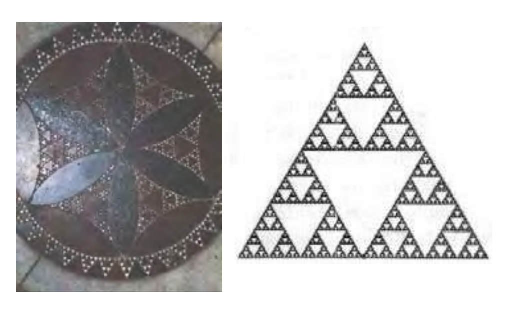

Figure (1-21) Floor of the Cathedral of Anagni Follows the Sierpinski Gasket (Sala, 2000)

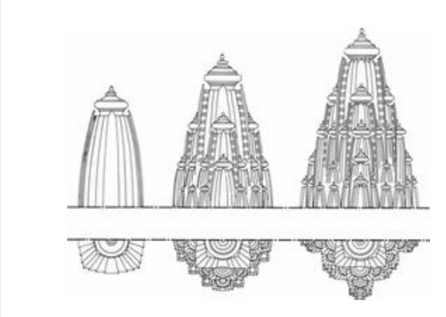

Figure (1-22) Three-Dimensional Fractal Generation of a Hindu Temple.
The main spire is surrounded by scaled down spires. (Joye, 2007)

The façade of Alhambra castle in Granada, Spain is another example of the fractal Islamic art and arabesque.

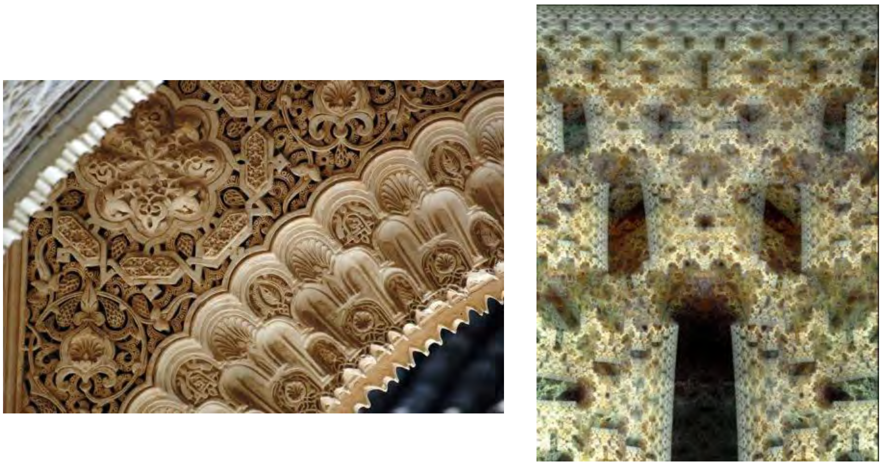

Figure (1-23) Fractal Design in Alhambra Palace, Granada, Spain.
Left: (http://en.wikipedia.org/wiki/File:Atauriques.jpg)
Right: (http://www.evolutium.net/islamicfractal.htm)

Another example is "Castel delmonte" raised by Federico II (1), where the outer shape, the courtyard and the eight small towers all have the octagonal shape (2).

The tangents of the octagon forming the inner courtyard intersect at the centers of the octagonal corner towers: they form an eight-pointed star whose tips lie at the centers of the towers as shown in Fig. (1-24).

Eight-pointed stars may also be drawn around the corner towers. The repetition of the basic 8-pointed star can be continued (3).

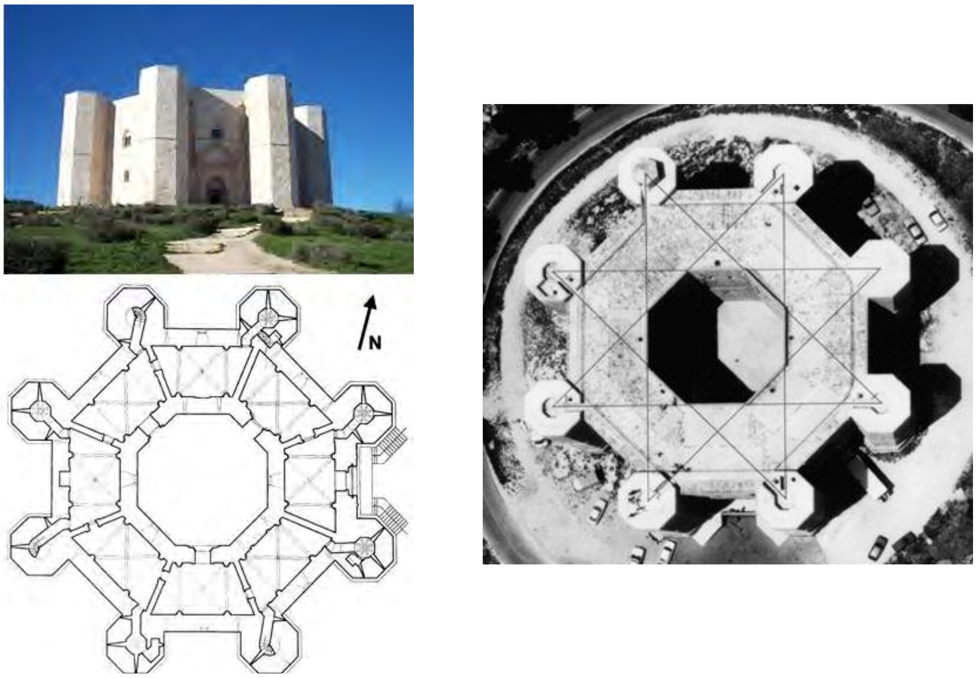

Figure (1-24)
The Castel Delmonte
Left: View and Plan
(www.castlesofmedievaltimes.com/castel-del-monte.html)
Right: The Continuing Eight Pointed Star
in the Design of Castel Delmonte *(Götze, 1996)*

The Palmer house of Frank Lloyd Wright shows a set of triangles, not only in the whole design, but also in the building details like roofs, furniture and even floor tiles (4) as shown in Figs (1-25) to (1-27).

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(1) Roman Emperor who lived between 1194 and 1250.
(2) SALA, S., "Fractal Models in Architecture: A Case Study”.
(3) Götze, R., "Friedrich II and the Love of Geometry”.
(4) Novak, N., "Emergent Nature: Patterns, Growth and Scaling in the Sciences".

Harris states that it is not the repetition of the form or motif but the manner in which it is repeated or its structure and nesting characteristics which are important (1). He has developed a fractal form which is similar to the Palmer House plan, shown in Fig. (1-26). In the first iteration, the seed shape is shown in darker gray and the three transformations are shown in lighter gray. In the second and third iterations the original seed shape is dropped out and the iterations are color coded in three shades of gray.

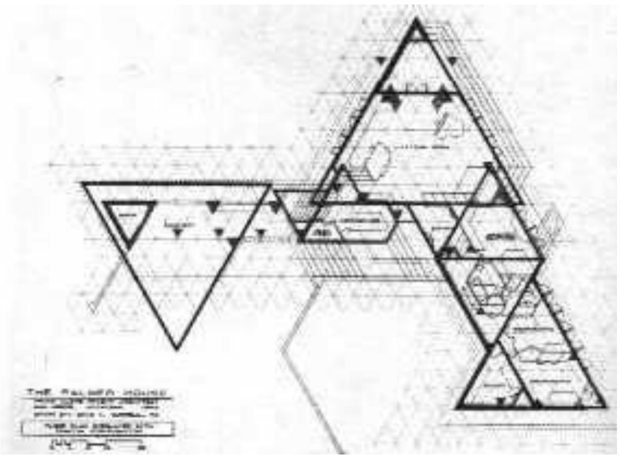

Figure (1-25): The Plan of Palmer House
(Sala, 2000)

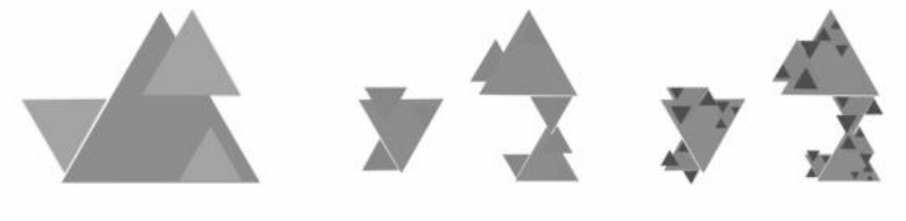

Figure (1-26) Iterations in the Triangles of Palmer House
(Harris, 2007)

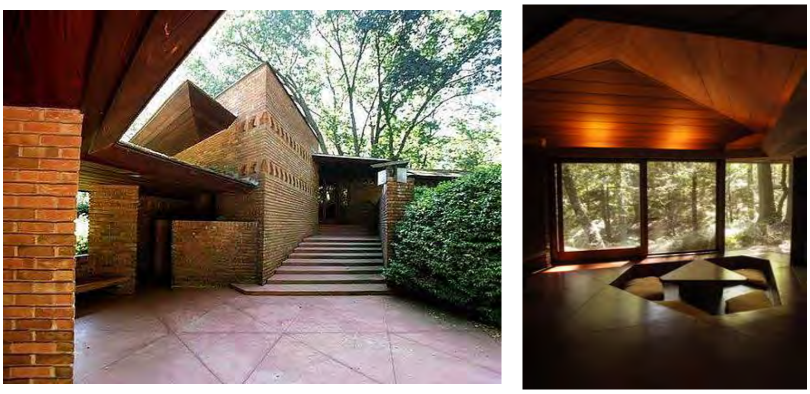

Figure (1-27)
Triangles in Masses, Furniture and Floor Tiles in Palmer House.
(www.nstandard.wordpress.com)

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(1) Harris, J., "Integrated Function Systems and Organic Architecture from Wright to Mondrian".

2-Large scale: the urban growth

Ba-ila:

Ba-ila settlement of Southern Zambia is an example of fractal architecture. Extended family's home takes the shape of a ring with a gate at one end. Near the gate there are small storage buildings. Moving around the ring, the buildings become larger dwellings, until the largest one, which is opposite to the gate; this is the father's house (1). Inside each family's house, there is a special place at the back of the interior. That is the household altar (2).

The same system takes place in the whole settlement where the family's dwelling rings move around in a larger scale. Entirely inside the settlement is the chief's house.

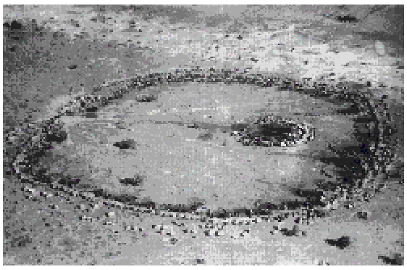

Figure (1-28): Aerial Photograph for the Ba-ila Settlement.
(www.classes.yale.edu)

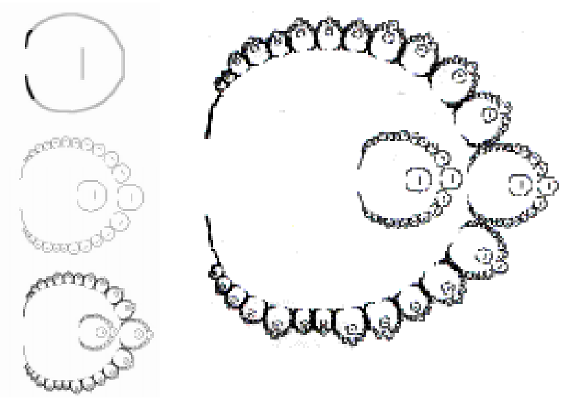

Figure (1-29): Plan of the Ba-ila Settlement.
(Eglash, R. et al, 2005)

Fibonacci Numbers and Golden Ratio:

Yahya reported that the common factor-between the pyramids in Egypt, Leonardo do Vinci's portrait of the Mona Lisa, sunflowers, the snail, the pine cone and our fingers-lies hidden in a sequence of numbers discovered by the Italian mathematician Fibonacci.

The characteristic of these numbers, known as the Fibonacci numbers, is that each number is the sum of the two numbers before it" (3).

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(1) www.classes.yale.edu
(2) Eglash, R. et al, "Fractals, Complexity, and Connectivity in Africa".
(3) Yahya, H., "The Measure of Beauty Created in Nature: The Golden Ratio".

Fibonacci numbers are: 0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, 377, 610, 987, 1597, 2584 …

Fibonacci numbers have an interesting property. When dividing one number in the sequence by the number before it, the result will be numbers very close to one another. In fact, the result is nearly fixed after the 13th in the series. This number is known as the "golden ratio (1)."
Table (1-1) views the calculations.

The golden ratio which equals 1.618 is found in the average human body as shown in Fig. (1-30).

Table (1-1): Calculations for Divisions of the Fibonacci Numbers. *(By researcher)*

Serial	Fibonacci Numbers, each divided by the number before it	
1	1/1	= 1
2	2/1	= 2
3	3/2	= 1.5
4	5/3	= 1.6
5	8/5	= 1.6
6	13/8	= 1.625
7	21/13	≈ 1.6153
8	34/21	≈ 1.6190
9	55/34	≈ 1.6176
10	89/55	≈ 1.6181
11	144/89	≈ 1.6179
12	233/144	≈ 1.61805
13	377/233	≈ 1.61802
14	610/377	≈ 1.61803
15	987/610	≈ 1.61803
16	1597/987	≈ 1.61803

$$\frac{\text{The height of a human being}}{\text{The distance between the navel and the foot}} = 1.618$$

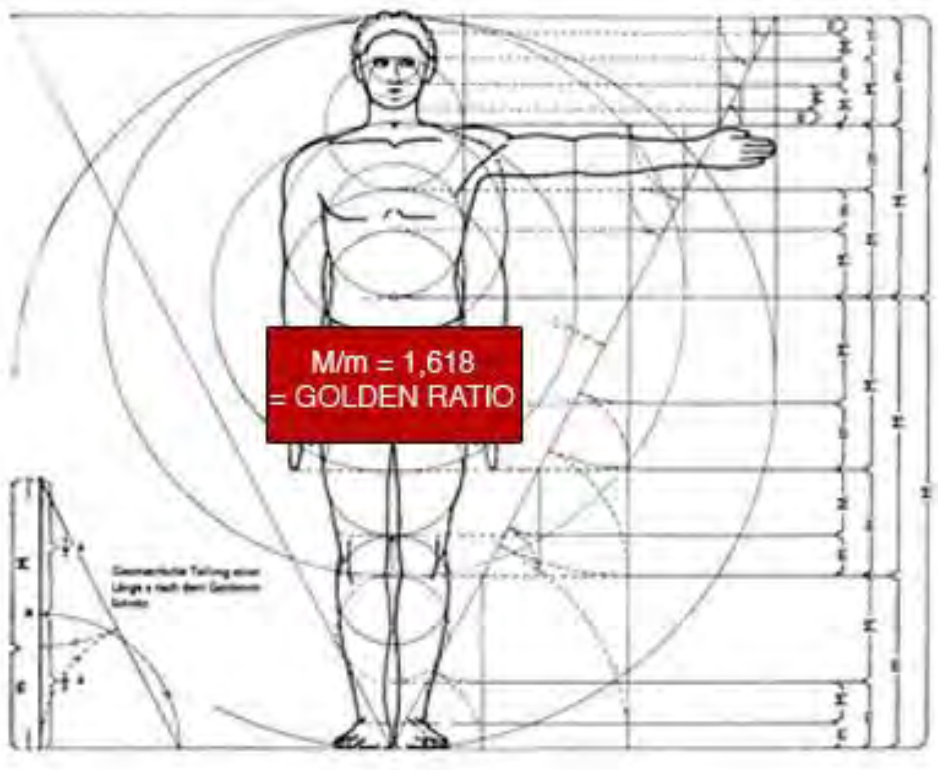

Figure (1-30) Fibonacci Numbers and Golden Ratio. *(Yahya, 2006)*

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(1) Yahya, H., "The Measure of Beauty Created in Nature: The Golden Ratio".

Golden Rectangles and Spirals:

The Golden Rectangle: is a rectangle which sides are 1.618 and 1, units long. Or 1: φ(one-to-phi), that is, $1 : \frac{1+\sqrt{5}}{2}$ or approximately 1:1.618.

The spiral based on the golden ratio is widely found in nature. Fig. (1-31). The spiral sequences on the sunflower and the pine cone are examples of Almighty Allah's flawless creation and how He has created everything with a measure, the growth process of many living things also takes place in a spiral form (1).

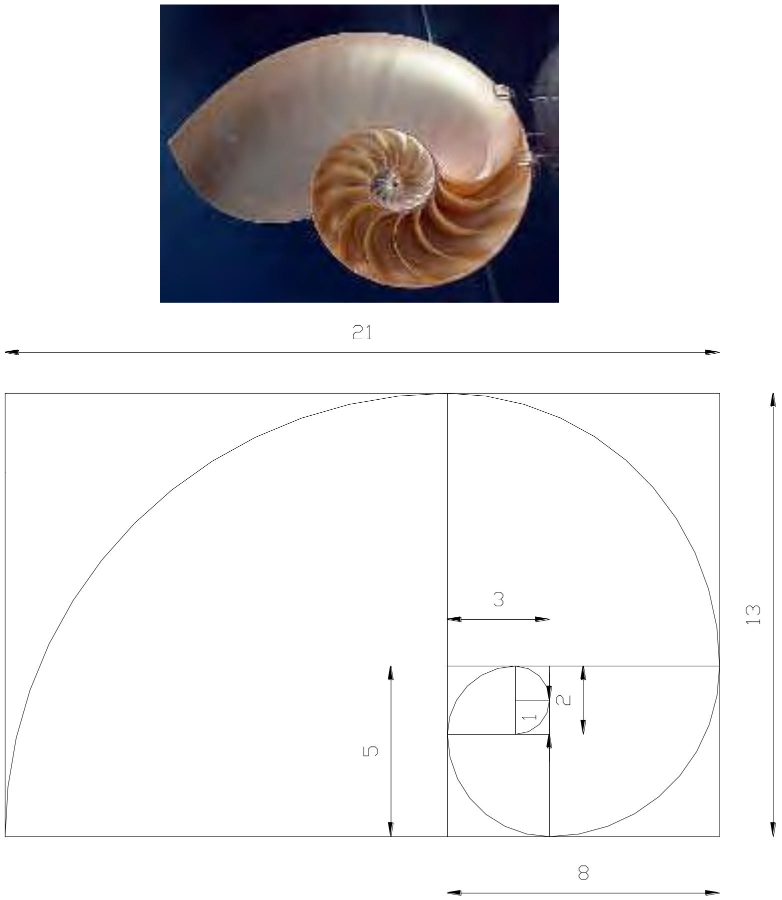

Figure (1-31): Golden Rectangle and Spiral.
Up (Biomimicry newsletter, 2006,) Down: (By researcher)

Yahya states that the curves in the spiral are always the same and the main form never changes no matter their size. No other shape in mathematics possesses this property.

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(1) Yahya, H., "The Measure of Beauty Created in Nature: The Golden Ratio".

Yahya also states that Three-dimensional forms that contain the golden ratio are very widespread in micro-organisms. Fig. (1-32) shows the relation between three dimensional forms like icosahedron and dodecahedron, and the golden rectangles, it shows that that the vertices of the golden rectangle meet the vertices of the icosahedron and the centers of the dodecahedron's faces.

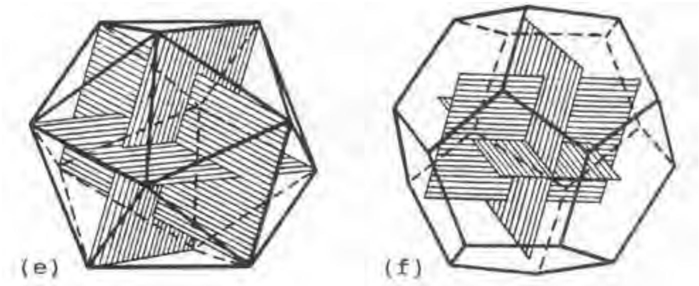

Figure (1-32): Icosahedron, Dodecahedron and the Golden Rectangles. *(www.philosophy.umd.edu)*

Many viruses have an icosahedron (1) shape. The best known of these is the Adeno virus. Fig. (1-33)

The dodecahedron (2) and icosahedron also appear in the silica skeletons of radiolarians, single-celled marine organisms shown in Fig (1-34), and in the diatoms.

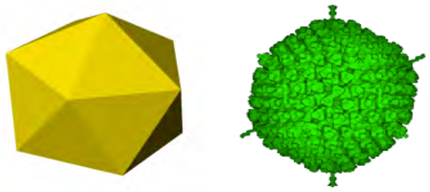

Figure (1-33): An Icosahedron and Adeno Virus. *(www.virology.net)*

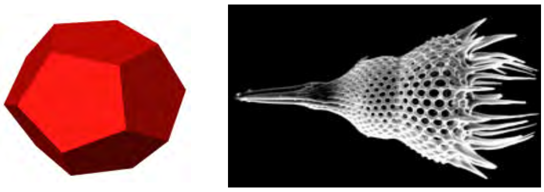

Figure (1-34): Dodecahedron and Radiolarian *(www.radiolaria.org)*

Diatoms are microscopic plant algae. Up to 10,000 of these living things, the largest of which is only 1 mm in diameter, can be found in 1 cubic centimeter of sea water. Some diatoms live in soil and even on walls where there is sufficient moisture. These golden yellowy-brown algae can be

---

(1) Icosahedron: Geometric Structure with 20 Equilateral faces, but usually referring to that of 20 equilateral triangular faces.

(2) Dodecahedron is any polyhedron with twelve faces, but usually referring to that of twelve regular pentagonal faces

found wherever there is light, heat, water, carbon dioxide and sufficient nutrients (1). They are shown in Fig. (1-35).

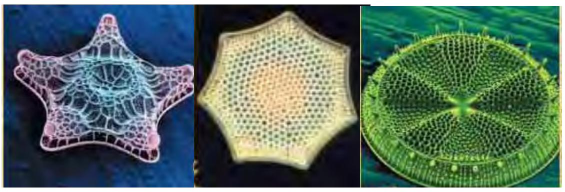

Figure (1-35): Diatoms.
(Yahya 2006)

Figure (1-36): The U.S. Pavilion-EXPO '76 Montreal.
(www.american-architecture.info)

Radiolaria and diatoms have inspired a great many large-scale architectural projects. The U.S. Pavilion at EXPO '76 in Montreal that is shown in Fig. (1-36) is just one example.

Why should we design fractally?

Two reasons could be found: Extension without planning ahead, and Beauty.

(1) Extension without planning ahead

According to Yahya, Klug-who discovered the shapes of viruses-said that the reason why viruses have shapes based on the golden ratio, is that the design of these viruses could be explained in terms of a generalization of icosahedral symmetry that allows identical units to be related to each other in a quasi-equivalent way with a small measure of internal flexibility (2).

The same reason appears in the words of Jeremy Faludi, where he states that self-similarity is a way of planning for several different scales at once.

Faludi states that Fibonacci spirals don't occur all over the place in nature because they're pretty, they occur all over because they're an algorithm that allows perpetual growth to any size without having to readjust or plan ahead (3).

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(1) Yahya, H., "Engineering in Nature", p.38.
(2) Yahya, H., "The Measure of Beauty Created in Nature: The Golden Ratio".
(3) Faludi, J., "Biomimicry for Green Design (A How to)".

So, designing fractally offers the possibility to extend the existing designs without having to set new designs.

In the plan of the Wolfsburg cultural center by Alvar Alto, shown in Fig. (1-37), the left part shows beauty, and it could be replicated to form extension if it wasn't for the adjacent parts.

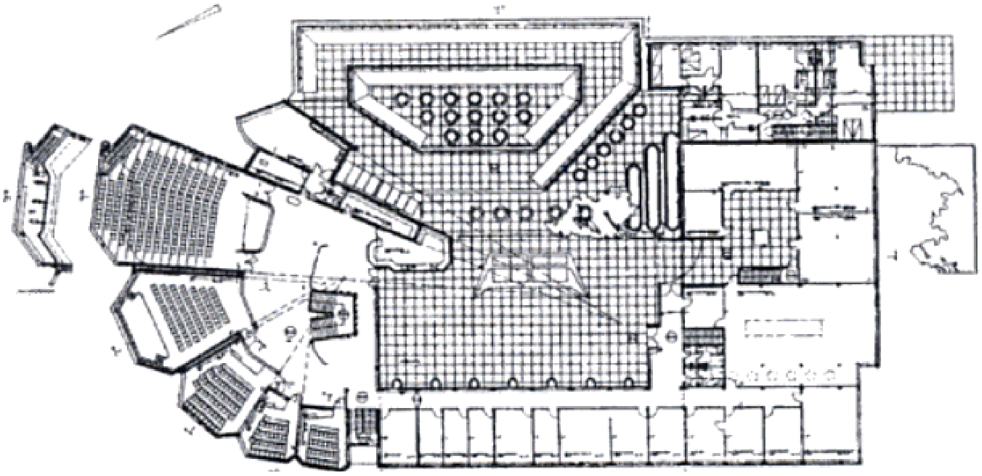

Figure (1-37): A Plan of the Wolfsburg Cultural Center by Alvar Alto.
(Bovill, 1996)

(2) Beauty

The golden ratio is an aesthetic rule well known and applied by artists; Works of art based on that ratio represents aesthetic perfection (1).

"Designing buildings with this knowledge automatically creates harmonizing, uplifting effects on those who experience them. When the structural lines of a building are designed according to the principles of harmonic proportions, a natural aesthetic beauty results—beauty that can benefit those who work, live, and play within those environments (2)."

Following the golden proportions found in nature ends up with beauty outputs, since we are also creatures of Allah who created these designs, no wonder that we respond to them positively.

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(1) Yahya, H., "The Measure of Beauty Created in Nature: The Golden Ratio".
(2) Watson, S., "Learning from Nature", p. 4.

1.2.12. Natural Designs Rely upon Swarm Intelligence:

Miller reported that ants might not be intelligent as individuals, but as colonies, they respond quickly and effectively to their environments. They do this with something called swarm intelligence.

The colony works with no management at all, it relies instead upon countless interactions between individual ants, such a system is described as self-organizing.

Miller also states that ants have inspired a company -that produces gas and oil from 100 sites, and delivers it to 6000 location-to determine which site to provide oil to which location.

One property of ants foraging (1), when they bring food back to the nest ,that the ants deposit a chemical substance called pheromone, to make it easy to other ants to recognize the way to get more food. The pheromone trail gets reinforced every time an ant goes out and comes back.

In the past, the drivers used to deliver oil from the nearest site to the location, regardless the electricity cost used to produce the oil in these sites. The costs were huge, as the prices of electricity were changing every 15 minutes in some areas. Mimicking the way ants choose their way for foraging has helped the company to achieve impressive savings (2).

This is how it could be seen:

For the ants:

The more reinforced the pheromone is in a route; the more this route is taken by ants to bring food, Even if it is too long.

For the company:

The less electricity cost to produce oil in a site, the more it is used -for the

---

(1) Ants that go out looking for food are called patrollers, while ants that go out to collect food are called foragers.

(2) Miller, P., "The Genius of Swarm".

moment -to support wherever locations are in need, Even if they were far apart.

The concept seems applicable when choosing material sources for a situ. A far site offering low material prices could be feasible than a near one offering high prices.

Towards Intelligent Architectural Community

A concept appears in Miller's article, that every one of us should take his role whether the others are taking their own roles or not.

Miller takes the honeybee as a model, shown in Fig. (1-38). He states that when a cold wind hits the bee hive, each single bee starts to shiver to generate heat, and, in the process, help to warm the nearby brood. She has no idea that hundreds of workers in other parts of the hive are doing the same thing at the same time to the benefit of the next generation.

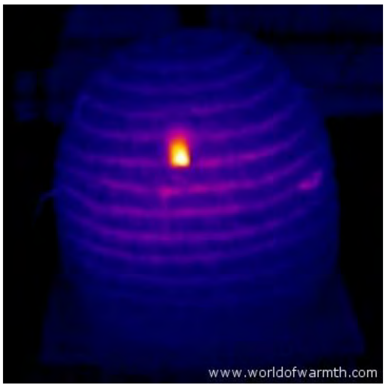

Figure (1-38)
An infrared Image of a Beehive.
We can see the warmth produced by the bees through the opening.
(www.asknature.com)

Architects are responsible on every detail of their designs; they should apply what they've learned, instead of waiting for someone to encourage them to apply what they already know.

Miller said that crowds tend to be wise only if individual members act responsibly and make their own decisions (1). Again, he focuses on the fact that a group won't be smart if its members imitate one another, or wait for someone to tell them what to do.

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(1) Miller, P., "The Genius of Swarm".

Buildings like trees and Cities like forests (1):

Buildings should be more like trees. They should be able to totally depend on natural sources, totally recycle their wastes, the same way the living organisms do.

Koelman figures his vision for a biomimetic building and biomimetic community, as follows (2):

Biomimetic Building:

1. Biomimetic building would be made from local materials with little energy input.
2. Biomimetic building would be naturally ventilated and illuminated
3. Biomimetic building would be using only current solar income instead of being connected to the electricity grid.
4. The majority of the building structure and materials would be re-usable at the end of its lifetime.
5. Landscaping would welcome animals and plants from local ecosystems and provide food for building occupants.

In a Biomimetic Community:

Koelman states that buildings would work together, each performing an ancillary functions to the benefit of all, with enough levels of redundancy so that, like a tropical forest, if one species or building fails temporarily, the web of others can support the flourishing neighborhood until it gets back on its feet.

The promising part in Koelman's words is the following sentence: "Organize a whole cluster of similar buildings in a particular locale and you have the beginnings of a futuristic, sustainable community."

Out of Koelman's vision, we can say that:

A set of living buildings is actually a living city, a living community.

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(1) The Expression belongs to William McDonough.

(2) Koelman, O., "The Biomimicry Way".

Summary:

Chapter one tackles Biomimicry, the new discipline. It starts with viewing and analyzing different definitions of the different terms, Biomimicry, Biomimetics and Bionics, which all express the new discipline, and the chapter ends up with the following definition: "Biomimicry is the study of the mechanisms of natural living organisms to perform their functions. "

In order to understand how God creatures work, twelve basic design principles found in nature were viewed, with examples from the world of conscious green architecture, whenever possible. This review aimed at figuring out the general concepts, which nature depends upon.

Conclusions:

1. There are basic principles that natural designs depend upon, they can be summarized as the following:
   a) Natural designs depend *totally on natural sources*, and *diversity of possibilities*. Among all sources, *Sunlight* has a special importance.
   b) Natural designs depends upon *total recycling*, where *waste* of a species *is food* for another, *symbiotic relationships* helps achieving the zero waste concept, and this leads to the principle: *don't foul your nest*, as wastes could really foul our nests.
   c) Natural designs respect the environmental *limits*, whilst ignoring these limits may also foul the nest. According to this respect, natural designs also *adjust to the here and now*, in another word, *they requires local expertise.*
   d) Natural designs use only the *necessary resources*, and *avoid overbuilding*
   e) Natural designs use the functional form and depend on fractal design where beauty hides, and the design may extend without planning ahead.

f) Natural designs depend upon network creation instead of linearity and rely upon swarm intelligence.

2. The levels of biomimicry can be classified in:
    a. Three general levels
        1) Form or Structure level
        2) Behavior or process level
        3) Ecosystem level.
    b. Nine Architectural levels:
        1) Concept
        2) Process
        3) Morphology
        4) Form
        5) Structure.
        6) Skin.
        7) Material.
        8) Expression.
        9) Symbolism.
3. Genius in natural designs widely depends on the precise nano morphology and structure, which was lately discovered due to the progress in the manufacture of microscopes. This may be the reason of the recent interest in biomimicry.

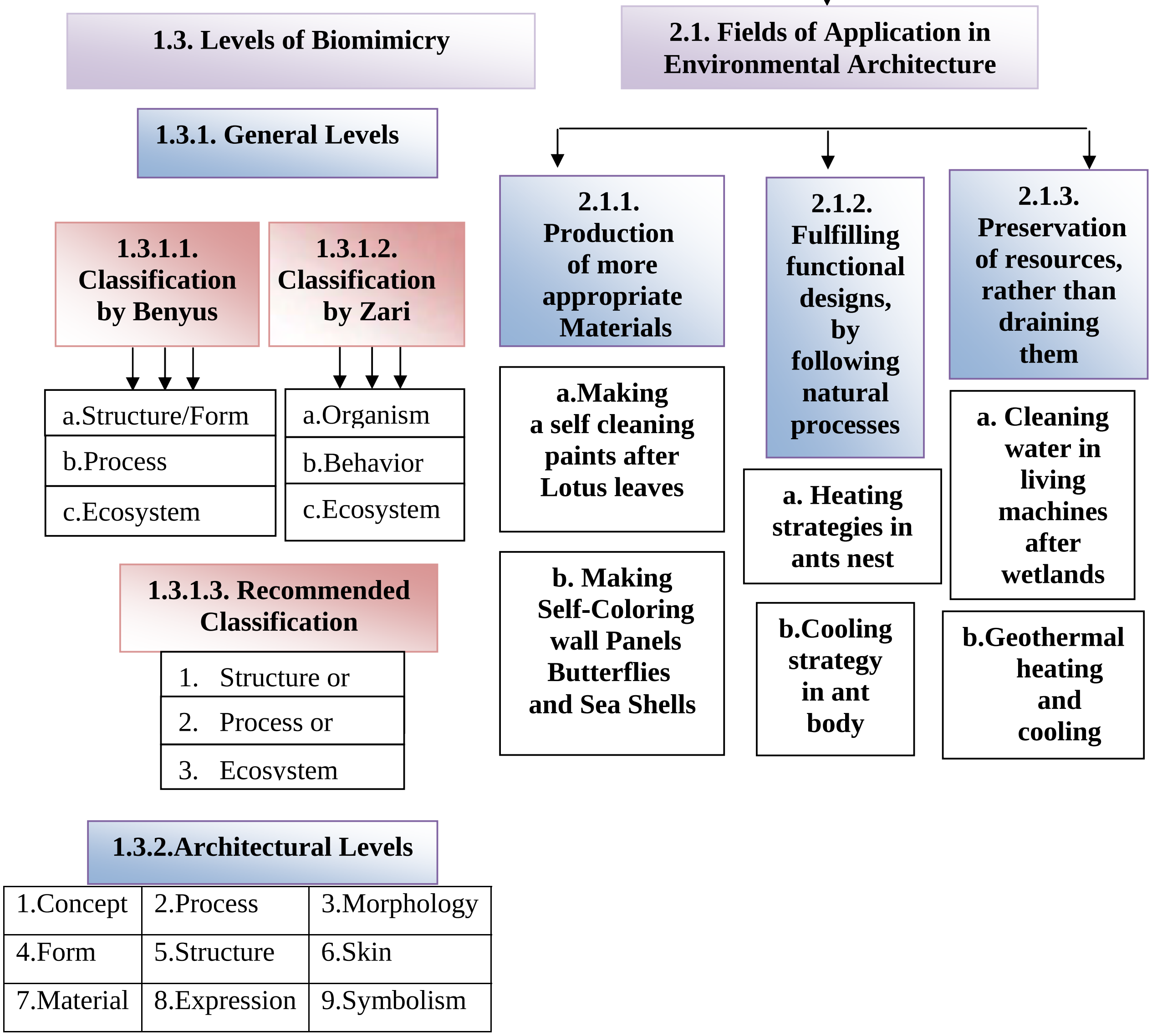
Chapter 2

BIOMIMICRY AS AN APPROACH FOR ARCHITECTURAL ENVIRONMENTAL DESIGN

"Architecture has much to learn
from systems that in evolving with their environment
display high levels of integration and functionality."
..Julian Vincent

Chapter 2

BIOMIMICRY AS AN APPROACH FOR ARCHITECTURAL ENVIRONMENTAL DESIGN



Chapter 2

BIOMIMICRY AS AN APPROACH FOR ARCHITECTURAL ENVIRONMENTAL DESIGN

Chapter Two
Biomimicry as an Approach for Architectural Environmental Design

2.1. Levels of Biomimicry:

Mimicking a living organism for example, is actually mimicking a certain aspect in this organism. This aspect may be the form of the organism, or the way in which the organism accomplish a function. The aspect that is mimicked is referred to as "The level of biomimicry".

Before viewing the levels of biomimcry, an important remark should be taken into consideration; that nature works in systems, that's why it will not be possible, in most cases, to deal with one level without considering the whole system.

2.1.1. General Levels:

Two classifications were set, one by Benyus and the other by Zari.

2.1.1.1. Classification by Ganine Benyus:

There are three levels of biomimicry, Janine Benyus indicated (1).

a. Structure or form Level.
b. Process Level.
c. Ecosystem Level.

a. Mimicking structure, or form :

Since the form of a creature enables it to accomplish its functions, mimicking that form enables us to accomplish the same functions. Mimicking the aerodynamic shapes that are found in nature is an example:

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(1) Conversation with Janine Benyus, the author of "Biomimicry: Innovation Inspired by Nature" at: (http://www.biomimicryguild.com/janineinterview.html)

Improving wind turbines after the whale blades:

The humpback whale blades have inspired the use of wind turbines with blades taking the same form to increase its efficiency.

The turbine blade decreases the wind resistance and hence makes the turbine move faster, the same way the whale blade decreases the wave resistance and hence makes the whale swim faster.

Humpback whale has large, irregular looking bumps called tubercules across their leading edges. Whereas sheets of water flowing over smooth flippers break up into myriad turbulent vortices as they cross the flipper, sheets of water passing between a humpback's tubercules maintain channels of fast-moving water, allowing humpbacks to keep their "grip" on the water at sharper angles and turn tighter corners, even at low speeds (1).

Figure (1-38) Wind Turbine after Whale Blade
Left Up: Humpback Whale.
Right: Humpback Whale Flipper.
(www.whalepower.com/drupal/)
Left Down: The Inspired Turbine. *(www.designboom.com/contemporary/biomimicry.html)*

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(1) www.asknature.org

Birds flying in "V" Shape (1):

Birds fly in a large "V" shape with one bird in the lead and others trailing behind in two lines, shown in Fig. (1-39). The main reason that this form decreases the drag that each bird experiences compared to if it were flying alone (2).

Figure (1-39)
V-shaped Flying Formation Expends Less Energy.
(www.aerospaceweb.org/question/nature/q0237.shtml)

The leader bird and the two birds in the back encounter the maximum drag, while the bird in the middle of each line of the V is in the best position. Fig (1-40).

When the leader tires, it will drop out of the lead position and another bird from further back will rapidly take its place, this cyclical rearrangement gives all birds the responsibility of being the leader as well as a chance to enjoy the maximum benefits of being in the middle of the formation (3).

However, mimicking the v-shaped flight can help when designing a high rise building.

Fig. (1-41) shows the 1450 Brickell office building (4) that exemplifies the concept.

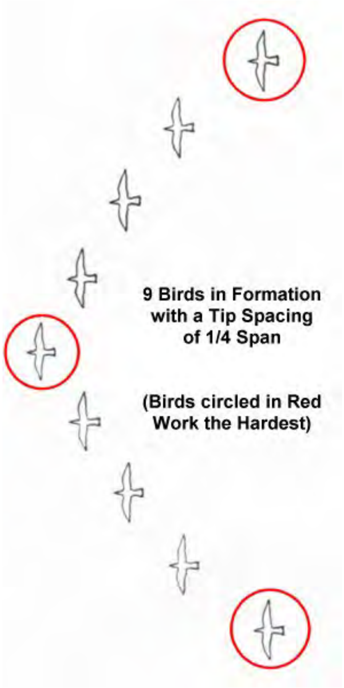

Figure (1-40)
The Distribution of Positions of the V-Shaped Birds Flight
(www.aerospaceweb.org/question/nature/q0237.shtml)

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(1) www.aerospaceweb.org/question/nature/q0237.shtml
(2) There is another reason that this orientation allows the birds to communicate more easily.
(3) Such a responsible behavior is worth mimicking.
(4) The 1450 Brickell office building is claimed to be the most wind-resistant glass-sided office tower in America (www.schwartz-media.com/tag/brickell-avenue). This is because it has large missile impact resistant glass on the whole tower building exterior. (www.1450brickell.com/). However, what concerns us here is its V-Shaped outline.

Something should be kept in mind that the outer envelope of building is exposed to unequal wind forces; the same like the birds encounter different drag forces.

Fig. (1-40) shows that the birds circled in red work the hardest, according to that, wind turbines can be placed in the points (A) and (B), in our buildings, as shown in Fig. (1-42).

Figure (1-41) The 1450 Brickell Office Building in Miami.
V-Shaped Building Illustrates the Concept.
(www.schwartz-media.com/tag/brickell-avenue/)

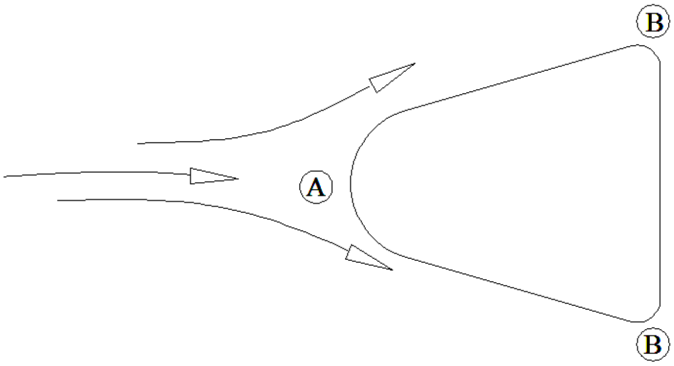

Figure (1-42) A Proposed Building Plan Decreases Drag.
(By researcher)
Like in birds, Point (B) and (A) encounters the maximum drag where turbines could be placed.

b. Mimicking process:

The scales of seed-bearing pine cones move in response to changes in relative humidity. The scales gape open when it is dry, releasing the cone's seeds. When it is damp, the scales close up (1).

As the humidity increases, the outside of each scale absorbs moisture. This causes them to swell, closing the scales and protecting the seeds from water, as extra moisture could cause them to mold before they are ready to grow.

When the air is dry, the outside of the scale dries out. This causes it to shrink, opening the scale to let the seeds fall out (2).

When cones are hanging on the tree, they are firm and closed. But as they ripen and fall to the ground, they open in order to release the seeds. This works because the scales of the cone consist of layers of two materials that react differently to humidity. When the cone dries out, the scale will bend, because one of its sides will expand more than the other (3).

Figure (1-43) Pine Cone Responding to Relative Humidity
(www.Ecosensorweb.dcu.ie)

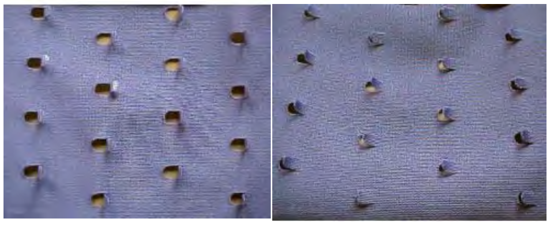

Figure (1-44) Multilayered Textile Automatically Opens When the Person Wearing it Starts to Sweat
(www.sebiology.org/publications/Bulletin/January_2007/Biomimetics.html)

Scientists have mimicked the process (4) in which the pine cone opens to produce clothing that opens alone in response to humidity (5).

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(1) Dawson, C., et al., “How Pine Cones Open”.
(2) http://thehappyscientist.com/science-experiment/pinecone-weather
(3) http://www.nynatur.dk/english/janine_benyus_eng.html
(4) Process is a series of actions, changes, or functions bringing about a result (www.thefreedictionary.com/process).
(5) http://www.sebiology.org/publications/Bulletin/January_2007/Biomimetics.html.

It is suggested that this process could be mimicked to serve producing self opening windows, which respond to humidity in wet areas.

c. Mimicking Ecosystem:

Filtration and desalination:

Mimicking properties of ecosystems like food web, Diversity, feedback loops and Symbiotic relationships that take place in wetlands when purifying sewage with Living machines.

Figure (1-45) Living Machine
Left: Part of the Living Machine at Oberlin College in Oberlin, OH, USA.
(Photo taken by Connor Lee in November 2005.www.en.wikipedia.org)
Middle: Living Machine Trade Mark
Right: City of Emmen Zoo, Netherlands, Indoor Living Machine System
(www.livingmachines.com)

Cleaning Water after Wetlands (1):

A biologist called John Todd (2) and colleagues developed an ecologically engineered technology, called "Living Machine", that purifies sewage or other polluted water, by mimicking the natural purification processes of ponds and marshes.

In practical application, a living machine is a treatment system designed to treat a specific waste stream by using diverse communities of bacteria and other microorganisms, algae, plants, trees, snails, fish and other living creatures.

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(1) www.naturaledgeproject.net
(2) John Todd is a Buckminster Fuller 2008 Challenge-winning. (www.challenge.bfi.org)

Todd's ecological purification system begins with the raw sewage entering an outdoor area containing tanks inhabited by a complex community of organisms. These tanks are then connected to a system of other tanks each with their own ecosystem specializing in a particular phase of decomposition and breakdown of organic and inorganic matter in the water.

After spending ten days in this filtering series of ecosystems the water flows clear into an artificial outdoor marsh or wetland to be reintroduced into the local hydrologic cycle.

The water can also be rendered drinkable by using an ultraviolet light or by passing the water through an ozone generator.

The process runs as follows (1):

- Bacteria consume the organic sewage and turn ammonia into nitrates, which is used as food for algae and fertilizer for duckweed (2).
- Zooplankton (3) and snails consume the algae.
- Fish eat the zooplankton.
- Floating plants soak up the leftovers.
- Bulrushes (4), cattails (5) and hyacinths (6) render the toxins harmless.
- Trees absorb heavy metals.
- The byproducts are decorative plants and small freshwater fish called minnows, both of which are sold.

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(1) www.biomimicry.info/wetlandwater
(2) Duckweed: stemless water plant
(3) Zooplankton: microscopic aquatic animals (protozoa, larvae, etc)
(4) Bulrushes: papyrus
(5) Cattails: wetland plants, typically 1 to 7 m tall
(6) Hyacinths: bulbous plant having fragrant bell-shaped flowers

The Eco-industrial Park" in Kalundborg, Denmark (1) is another example, as it mimics the recycling process in nature.

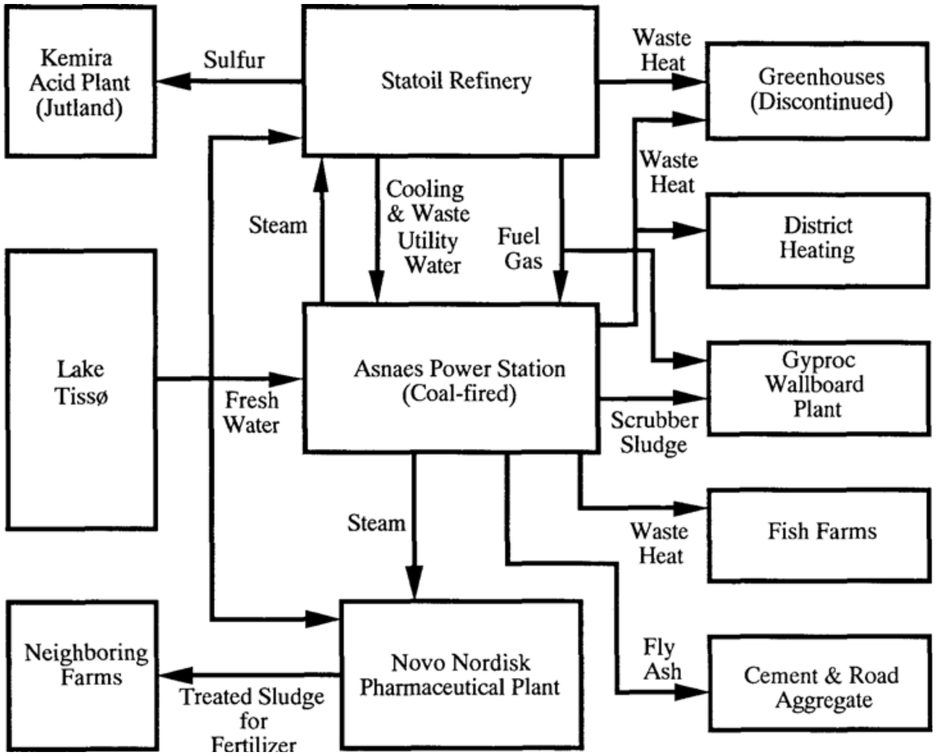

Figure (1-46) Eco-Industrial Park in Kalundborg, Denmark
(www.johnehrenfeld.com/Kalundborg.pdf)

Overlapping Between Biomimicry Levels:

Overlapping may occur between the three levels, for example:

- Water filtration in houses mimicking wetlands could be seen as:
  - Process mimicking: As we mimic the process in which the filtration occurs in wetlands.
  - Ecosystem mimicking: As we mimic a property of an ecosystem as the feedback loops exist.
- The V-formation of the birds' flight could be seen as:
  - Form mimicking
  - Behavior mimicking.

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(1) Different illustration was previously viewed at p. 16.

2.1.1.2. Classification by Pedersen Zari (1):

Zari sets the levels of Biomimicry as follows:

a. Organism level
b. Behavior level
c. Ecosystem level

Like Benyus, Zari had set three levels of biomimicry, but had named the first the Organism level, the second, the Behavior level, and they had both agreed on the third, the Eco-System level.

Within each of these levels, Zari believes that a further five possible dimensions to the mimicry exist. The design may be biomimetic for example in terms of:

- What it looks like (form)
- What it is made out of (material)
- How it is made (construction)
- How it works (process)
- What it is able to do (function).

Zari states that some overlap between different kinds of biomimicry is expected to exist. For example, a series of systems that is able to interact like an ecosystem would be functioning at the ecosystem level of biomimicry. The individual details of such a system may be based upon a single organism or behavior mimicry.

In table (2-1), the way in which Zari had explained the levels of Biomimicry on the famous example of termite mound will be viewed.

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(1) Zari, M., "Biomimetic Approaches to Architectural Design for Increased Sustainability".

Table (2-1): Framework of Biomimicry Levels. *(Zari, 2007):*

Levels Of Mimicry / Dimensions	**Organism level** (Mimicry of a specific organism)	**Behavior level** (Mimicry of how an organism behaves or relates to its larger context)	**Ecosystem level** (Mimicry of an ecosystem)
Form	The building *looks* like a termite.	The building looks like it was ***made by*** a termite; a replica of a termite mound for example	The building looks like an ecosystem (a termite would live in)
Material	The building is *made from* the same material as a termite; A material that mimics termite exoskeleton / skin for example.	The building is made from the same materials that a termite *builds with;* Using *digested fine soil* as the primary material for example.	The building is made from the same kind of materials that (a termite) ecosystem is made of; It uses *naturally occurring* common *compounds and water* as the primary chemical medium for example.
Construction	The building is *made* in the same way as a termite; It goes *through various growth cycles* for example.	The building is made in the same **way** that a termite would *build in;* *Piling earth* in certain places at certain times for example.	The building is assembled in the same way as a (termite) ecosystem; Principles of succession and increasing complexity over time are used for example.

Table (2-1) continued:

Levels Of Mimicry / Dimensions	**Organism level** (Mimicry of a specific organism)	**Behavior level** (Mimicry of how an organism behaves or relates to its larger context)	**Ecosystem level** (Mimicry of an ecosystem)
Process	The building *works* in the same way as an individual *termite;* It *produces* hydrogen efficiently through meta-genomics for example.	The building *works* in the same way as a termite *mound would*; by careful orientation, shape, materials selection and natural ventilation for example, or it mimics how termites *work together*.	The building works in the same way as a (termite) ecosystem; It captures and converts energy from the sun, and stores water for example.
Function	The building *functions like a termite* in a larger context; It *recycles* cellulose waste and creates soil for example.	The building functions in the same way that it would *if made by termites;* Internal conditions are regulated to be optimal and thermally stable for example. It may also function in the same way that termite mound does in a larger context.	The building is able to function in the same way that a (termite) *ecosystem would* and forms part of a complex system by utilizing the relationships between processes; It is able to participate in the hydrological, carbon, nitrogen cycles etc in a similar way to an ecosystem for example.

Some cons could be observed in Zari classification, as the following:

1. The word behavior is not sufficient enough to express the second level. Because the respiration in insects for example cannot referred to as a “behavior” but rather a “process”. So it is preferable that the second level would be:”Behavior and process”.

2. The ecosystem has no “form”, it is seen that it is incorrect that the framework has included the Ecosystem in this dimension. However, the difference between the behavior and ecosystem level in this dimension is still not distinguished.

Zari refers to the termite mound in both cases, as follows:

In the “form’ dimension, Zari wrote: ”The building looks like it was made by a termite” and “the building looks like an ecosystem, a termite would live in.” and both sentences actually refer to the termite mound as shown in table (2-2).

Table (2-2): Form Dimension in Biomimicry Levels. *(Zari, 2007):*

Levels Of Mimicry Dimension	**Organism level** (Mimicry of a specific organism)	**Behavior level** (Mimicry of how an organism behaves or relates to its larger context)	**Ecosystem level** (Mimicry of an ecosystem)
Form		*The building looks like it was made by a termite;* a replica of a termite mound for example	*The building looks like an ecosystem (a termite would live in)*

3. Zari has gone much further in details to the extent that it is difficult to differentiate between some items of his classification. For example, it’s difficult to differentiate between the “process” dimension and the “function” dimension, as shown in table (2-3).

Table (2-3): Process and Function Dimension in Biomimicry Levels. *(Zari, 2007)***:**

	Organism Level	**Behavior Level**	**Ecosystem Level**
Process	The building *works* in the same way as an individual termite.	The building works in the same way as a termite *mound would;*	The building *works* in the same way as a (termite) ecosystem;
Function	The building *functions* like a termite in a larger context;	The building functions in the same way that it would *if made by termites;*	The building is able to function in the same way that a (termite) *ecosystem would* and forms part of a complex system by utilizing the relationships between processes;

- <u>In the organism level</u>:

It’s hard to differentiate between the way that the ant works, and the way that the ant *functions*.

- <u>In the behavior level</u>:

In the “process” dimension he wrote:” The building *works* in the same way as *a termite mound would;”*

In the “function” dimension we read: The building *functions* in the same way that it would *if made by termites;*

In fact, both dimensions simply express the termite mound.

- <u>In the ecosystem level:</u>

The undifferentiated expressions: “the building works” and “the building is able to function.” appear again.

2.1.1.3. Recommended General Classification:

Out of the previous two classifications, it is preferable that the levels of biomimicry would be:

1. Form or Structure Level.
2. Behavior or Process Level.
3. Ecosystem Level.

This is because:

- The organism level was excluded because it is not accurate, as it can describe the second level, behavior too.
- Behavior is different from Process so both of them should be mentioned.

Those levels are general. They can be applied to any field. The coming section figures out Biomimicry levels that specifically applied to the field of architecture.

2.1.2. Biomimicry Levels in Architecture (1):

Whether an organism or a property in an ecosystem is mimicked, In Architecture, the level of biomimicry could be one or more of the following:

1- Concept
2- Process or behavior
3-Morphology
4- Form
5- Structure
6- Skin
7- Material
8-Expression
9- Symbolism

1-Concept:

When an ecosystem property like “Closed Loop Cycles" or "Symbiotic Relationship" is mimicked, then the concept of “cycling” or “symbiosis” is actually being mimicked.

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(1) More examples of the levels of mimicry in architecture are shown in appendix 4 “Biomimetic Buildings”

Water recycling in buildings is mimicry to the concept of "Closed Loop Cycles" in nature. The tower of tomorrow (1) is an example.

Also the “Eco-industrial Park” in Kalundborg, Denmark (2), shows another example of the mimicry of an ecosystem property, which is concept mimicry in the first place.

A set of industries are sharing their wastes, so the waste of one industry becomes an input to another. This process mimics the concept of symbiotic relationships in nature

2- Process or Behavior:

The ventilation process in termite mounds was mimicked in Eastgate building in Zimbabwe (3). The termites need to keep their temperature and humidity within narrow limits and to do this the mounds have a ventilation system which uses the wind and narrow passages running up the mound just under its surface to maintain the right conditions.

The mimicry here is process mimicry, the process of ventilation in which air moves in a way that keeps a constant temperature inside.

Figure (1-47):
Termite Mound
(http://www.n100best.org/innovation/case01.html)

3- Morphology:

The morphology is the form and structure of an organism or any of its parts (4). Nowadays, it is possible to understand the morphology and nanostructure of many organisms, due to the progress of microscopes industry. The example that will be viewed here is the nano structure of mother of pearl.

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(1) Shown at p. 14
(2) Shown at p. 16
(3) Previously viewed at p. 21.
(4) Merriam-Webster dictionary. (http://www.merriam webster.com/dictionary/morphology.

The design is the key reason to why the abalone shell is so tough (1); it is 3,000 times stronger than normal forms of the mineral it is made out of, the calcium carbonate (2).

The nano structure of abalone shell can be described as ‘Brick and mortar’. The abalone consists of layer upon layer of Aragonite -a naturally occurring form of calcium carbonate -between sheets of protein (1).

The organism builds multistory building, laying down one storey after another, but each slightly offset from the one below to accomplish the interlocking brick-wall motif (3), as shown in Fig. (1-48). According to this composition, it becomes difficult for any rupture to spread, as the strength of a shock fades while moving from class to another.

Fig. (1-49) shows that between each plate of calcium carbonate is a much thinner sheet of protein. When the abalone shell is pulled apart, the protein stretches dramatically to resist the force (4).

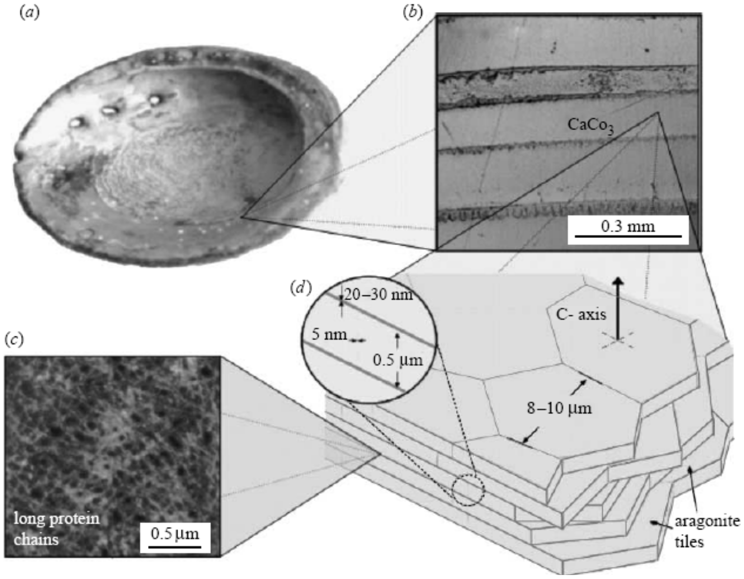

Figure (1-48) Hierarchy of the Abalone Structure.
(a) Entire Shell, (b) Mesostructure with Mesolayers, (c) Nanostructure Showing Organic Interlayer and (d) Microstructure with Aragonite Tiles
(Bahusan, 2009)

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(1) www.Treehugger.com
(2) Forbes, P., “The Gecko’s Foot”, p. 140.
(3) Benyus, J., “Biomimicry: Innovation Inspired by Nature”, p.102.
(4) Forbes, P., “ibid”, p. 140.

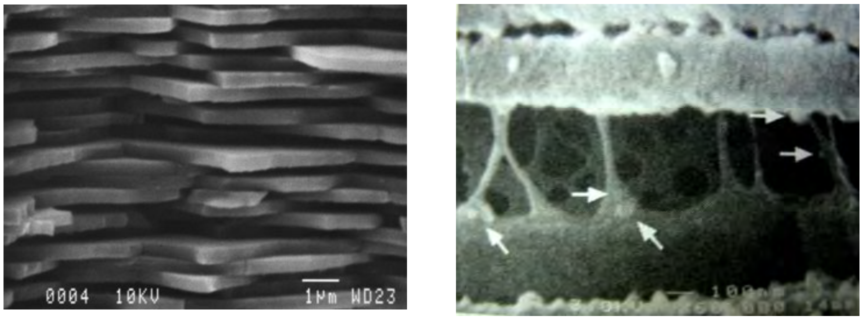

Figure (1-49) The Micro Structure of the Abalone Shell.
Left: The Stacked Layers of Calcium Carbonate Crystals Revealed under the Microscope.
Right: Thin Sheets of Proteins between the Plates of Calcium Carbonate that Stretch when Necessary.
(Forbes, 2006)

4- Form:

Beavers build concave shelters. This shape is best able to withstand the water pressure, and it is claimed that the beaver is the source of inspiration to the concave dams (1).

The Hoover Dam in Colorado is an example. It is shown in Fig. (1-50).

Figure (1-50) Concave Dams after Beaver Dam.

Left: The Beaver Dam.
(www.livingindryden.org/2005/04/)
Right Up: The Beaver.
(www.open.salon.com/blog/chris_k/recent/page/2)
Right Down: The Hoover Dam.
(www.thomasnet.com/articles/electrical-power-generation/hydroelectric-power)

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(1)Yahya, H., “Beaver: Skilful Dam Constructor”.

5- Structure:

This level may be the most rich with architectural examples. Architects like Buckmenster Fuller, Frai Otto, Frank loiid Wright and many others are famous for their architectural works inspired by nature.

- **Steel Frames**

  The landscape designer Joseph Paxton designed the crystal palace in 1850. Paxton drew his inspiration from Victoria amazonica, a species of water lily, which has huge leaves that are strong enough for people to stand on, despite its fragile appearance (1).

Figure (1-51): Cristal Palace after Water Lily
Left: Crystal Palace, Right: The Water Lily,
Middle: Supporting Members of Water Lily.
(Yahia, 2006)

- **Tensile construction:**

  The spider thread is a constructive miracle of nature. They are much more resistant than the steel wires of the same diameter (2). This marvelous technique has been imitated in many structures to cover wide areas. Some of these include the Jeddah Airport’s Pilgrim Terminal.

Figure (1-52): Tensile Constructions after Spider Web
Left: Spider Web
(http://www.knowledgerush.com/kr/encyclopedia/Spider_silk/)
Right: Jeddah airport’s Pilgrim Terminal
(http://www.denardis.com/specialimage/jeddah.html

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(1) Yahya, H., "Biomimetics: Technology Imitates Nature".
(2) Podborschi, V., and Vaculenco, M., “Study of Natural Forms: The Source of Inspiration in the Product Design”.

- **Load Distribution in Human Body:**
  - **Arches of the Foot :**

Human foot has three arches, the medial arch which is the biggest, the longitudinal arch which runs parallel to the medial arch on the outside of the foot, and the metatarsal arch reaches across the forefoot. These arches provide support just like arches that the Romans built when they made the aqueducts 2000 years ago. The structure of an arch makes it possible for the loads to be supported with the least amount of effort and material.

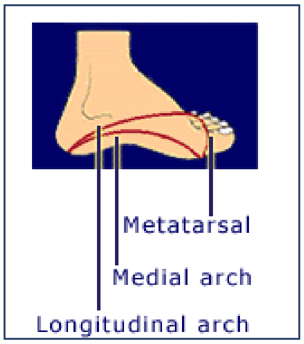

Figure (1-53): Three Arches of the Foot
(www.stepforward.com.au)

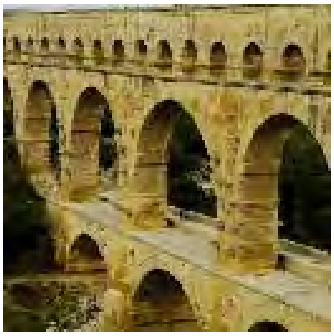

Figure (1-54): Aqueduct in France, at the Roman Era
(www.whc.unesco.org)

  - **Eiffel Tower after Thigh Bone:**

The design of Eiffel tower was based on the concept of load distribution in the thigh bone, which was discovered by the Swiss engineer Karl Cullmann in1866 (1).

Cullmann was in a visit to his friend, the anatomist Hermann Meyer (2), who had sectioned a human femur, revealing its internal structure, Culmann realized instantly that the fibers were taking up the lines of tension and compression produced when the bone was loaded. He exclaimed: “That’s my crane” (3) Cullmann’s crane shown in Fig. (1-55) took similar form.

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(1) Yahya, H., "Biomimetics: Technology Imitates Nature", p.151.
(2) Previously mentioned at p.23.
(3) Forbes, P., “The Gecko’s Foot”, p. 208.

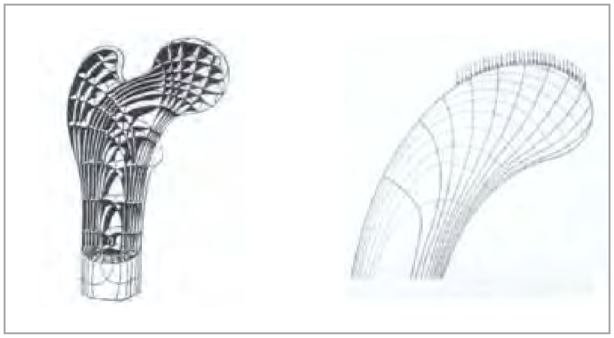

Figure (1-55): Load Distribution in the Thigh Bone.
Left: Human Thigh Bone or Femur.
(Chiu and Chiou, 2009)
Right: Culmann's Crane Taking Similar Form of the Femur Load Distribution. *(Forbes, 2006)*

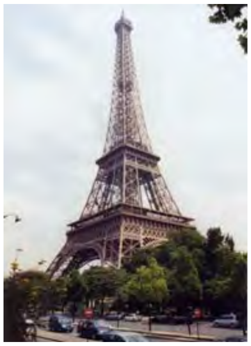

Figure: (1-56):
Eiffel Tower.
(www.greatbuildings.com.)

o Dancing Buildings after Back Bone:

The same concept of using material in paths where loads are being transmitted have also led to the modern designs of dancing buildings.

Figure (1-57): Dancing Buildings after Human Back Bone.
Left: Human Back Bone. (*http://www.live-well.org.uk/spinal_health.html)*
Buildings From Left to Right:
Dancing House in Prague by Frank Gehry. (*www.galinsky.com)*
Dancing Tower in Dubai by Zaha Hadid. (*www.yankodesign.com)*
W Towers in Czech Republic by Bjarke Ingels Group. (*www. archema.org)*

- **Shell Construction:**

The shells of mussels and oysters have irregular shapes which allows the shells, despite being very lightweight, to withstand enormous pressure (1).

Figure (1-58): The Royan Market after the Oyster Shell
(Yahia, 2006).

- **Gridshell Construction:**

Dragonfly wings are one three-thousandth of a millimeter thick. Despite being so thin, they are very strong since they consist of up to 1,000 sections. Thanks to this compartmental structure the wings do not tear, and are able to bear the pressure that is formed during flight. The roof of the Munich Olympic Stadium, which was built in 1972 was designed by Frei Otto along the same principle (1).

Figure (1-59): The Munich Olympic Stadium after the Dragonfly Wings.
(Yahia, 2006)

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(1)Yahya, H., "Biomimetics: Technology Imitates Nature".

- **Domes after Radiola and Diatombs**

  Radiola and diatombs inspired many architects, amoung the famous examples is The U.S. Pavilion at EXPO ’76 in Montreal by Buckminster Fuller (1).

Figure (1-60): Domes after Radiolaria and Diatoms
(Yahya 2006)

- **Tree structure**

Johnson Wax Building by Frank Lloyd Wright and many high rise buildings mimicked the system in which loads are transmitted through a central core of a tree.

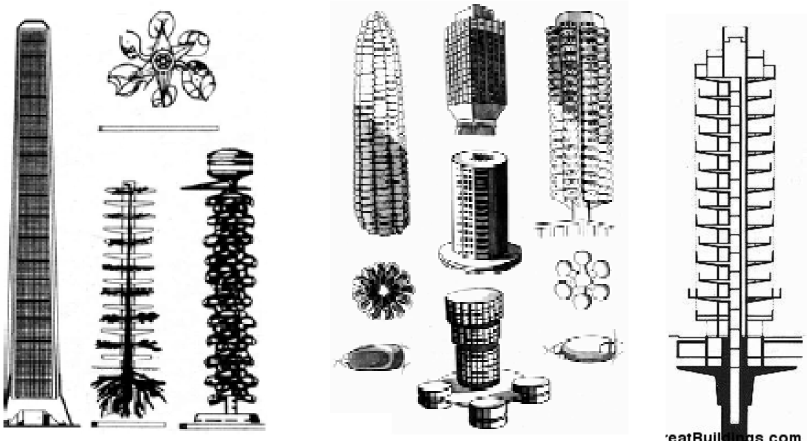

Figure (1-61): Johnson Wax Building and High Rise Towers after the Growth Form of a Tree and Stem of Cereals
(Podborschi and Vaculenco, 2005)

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(1) Yahya, H., "Biomimetics: Technology Imitates Nature", p.153.

- **Flexible Joints:**

Nicholas Grimshaw & Partners' design for the Waterloo International Terminal is another example of structure mimicry. The glass panel fixings that make up the structure of the building mimic the flexible scale arrangement of the Pangolin.

These fixings made the building able to respond to the air pressure changes due to the in and out movements of the trains (1).

Figure (1-62): Waterloo International Terminal Covering Joints after the Pangolin Flexible Joints.
a. The Pangolin. (www.panoramio.com/photo/10208132)
b. The building. (www.hughpearman.com/articles/grimshaw.htm)

6- Skin:

In the Hydrological Center for the University of Namibia, the outer Surface of the barrier facing the fog direction mimics the skin of the Namibian desert beetle (2).

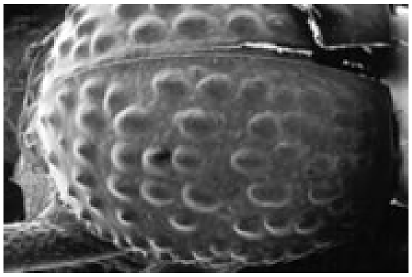

Figure (1-63): Microscopic Detail of the Beetle's Back
(http://www.newscientist.com/article/dn1508-beetle-fogcatcher-inspires-engineers.html)

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(1) Zari, M., "Biomimetic Approaches to Architectural Design for Increased Sustainability". More details about the building is viewed at the appendices, at p. 251.

(2) The skin of the desert beetle was previously viewed at p. 12.

In that barrier, Matthew Parkes of KSS Architects has mimicked the ability of the desert Namibian beetle skin to capture moisture from the moving fog, as it lives in a desert with negligible rainfall (1).

Fig (1-64) illustrates the building. The barrier or the nylon-mesh sail (A) collects the fog as it rolls in. As the mesh becomes saturated, gravity feeds the water into an underground tank (B), where it joins pumped in seawater (C) that has been desalinated using photovoltaic panels (D) (2).

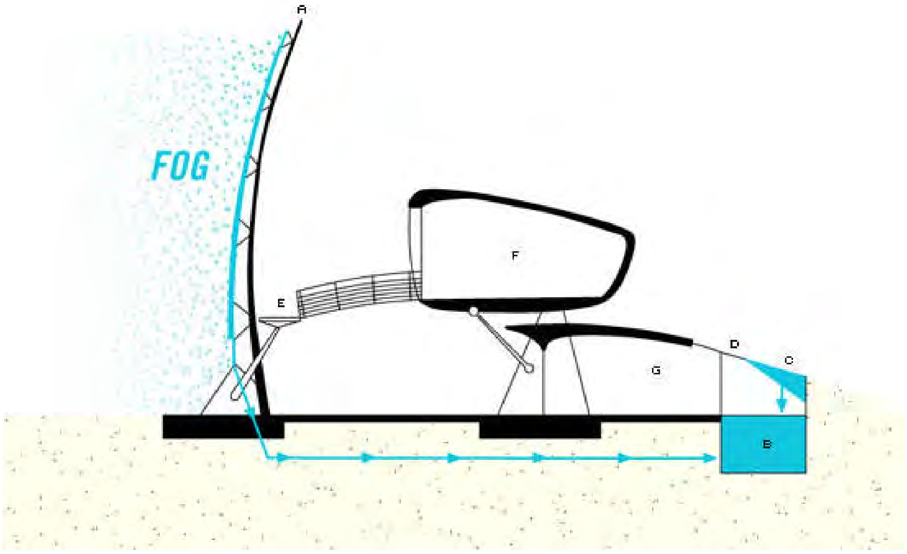

Figure (1-64): Hydrological Center for the University of Namibia. after the Namibian Desert Beetle
(A)A nylon-mesh sail. (B) An underground tank. (C) Pumped in and Desalinated sea water. (D) Photovoltaic panels. (E) Footbridge. (F) Class room. (G) Office space. (www.metropolismag.com/html/content_0502/ob/model.html)

7- Materials:

The Use of Two Materials with Variable Response to Humidity:

When mimicking the pine cone (3) to make openings that open alone in response to relative humidity, then actually the materials, in which the pine cone is made from, are those that are mimicked.

Those materials have certain properties that cause the inner and outer layers respond to humidity in different degrees.

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(1) Zari, M., “Biomimetic Approaches to Architectural Design for Increased Sustainability”.
(2) www.metropolismag.com/html/content_0502/ob/model.html.
(3) Previously explained at p. 46, and illustrated in fig. (1-43).

It is seen that the use of a bi-metallic strip is a replica of this concept, except that the latter works on temperature basis instead of working on humidity basis.

The bi-metallic strip consists of two strips of different metals which expand at different rates as they are heated, usually steel and copper. The strips are joined together throughout their length either riveting or welding. The different expansions force the flat strip to bend one way if heated, and in the opposite direction if cooled below its normal temperature (1).

This concept could be used to control the movement of hundreds of greenhouses roofs in a farm according to the temperature, instead of computerized solutions that are costly and unreliable (2).

The bimetallic strip bends and lifts the frame in high temperature, and straightens to lower the roof when the temperature drops.

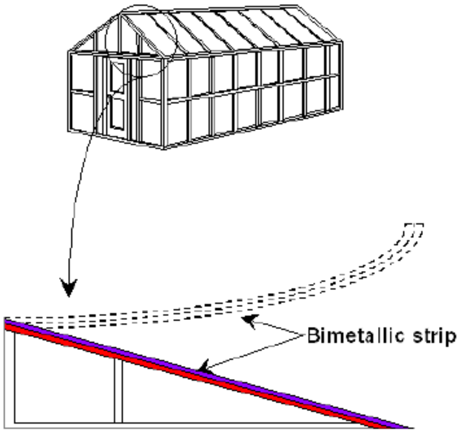

Figure (1-65): Greenhouse Frame Made of Bimetallic Strip.
(Fey and Rivin, 1998)

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(1) www.encyclo.co.uk/define/Bi-metallic%20strip
(2) Fey, V., and Rivin, E., "Ideal System, or Why the Question *What?* May Be More Important Than the Question How?"

8- Expression:

Bahá'í House of Worship in Delhi, India(1):

Also known as The Lotus Temple, and "Mashriqu'l-Adhkár" (2) which means in Arabic "Dawning-place of the remembrances of God". The designer Fariborz Sahba chose the form of a lotus in an attempt to bring out the concept of purity, simplicity and freshness of the Bahá'í Faith (3).

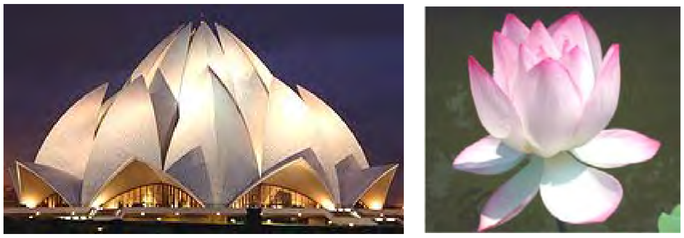

Figure (1-66): Lotus Temple after Lotus Flower.
Left: Lotus Temple.
(www.eso-garden.com/index.php?/weblog/bahai_lotus_temple/)
Right: Lotus Flower.
(www.aleppos.net/forum/showthread.php?t=30669)

It seems like it gives the impression of many entities turning to one God. Bahá'í Holy Writings said: "There is one God; mankind is one; the foundations of religion are one (4)."

This expression could be strongly received after reading that the Baha'I faith permits people from different religions to enter the Baha'I temples.
"a temple dedicated to the Oneness of God, the Oneness of religions, and the Oneness of mankind, in which people of all backgrounds are welcome (5)".

However, bringing out the concept of purity, simplicity and freshness of the Bahá'í Faith could be classified as symbolism, not expression.

"A*rchitect Fariborz Sahba chose the lotus flower as a symbol for the Baha'I belief in the potential purity of the human spirit, he chose it as a metaphor for*

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(1) More pictures of the temples are viewed in the appendices.
(2) In Arabic: (مشرق الأذكار)
(3) www.bahaindia.org/temple/architecture.html
(4) www.bahaindia.org/temple/index.html
(5) www.sahbaarchitect.com/flash.html

the truth that out of the "murky waters" of our collective history of ignorance and violence we will arise to create a new age of peace and universal brotherhood ⁽¹⁾."

9- Symbolism:

TWA Terminal:

Designed by Eero Saarinen, in 1962, resembling a bird ready to fly, the design aims at giving an expression of flying.

Figure (1-67): Expression Mimicry in TWA Terminal
Left: A Bird Ready to Fly. *(www.cruzio.com)*
Right: TWA Terminal. *(www.greatbuildings.com)*

The Atrumium:

A symbol for Brussels, designed by André Waterkeyn for the International Exhibition of Brussels in 1958 (2).

The building is symbolizing a cell of an iron crystal magnified 165 billion times (3). It includes restaurants; museum and the visitors have a panoramic view of the city from the top.

Figure (1-68): The Atumium
(http://unusual-architecture.com/atomium-brussels-belgium/)

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(1) www.sahbaarchitect.com/flash.html
(2) http://www.atomium.be/?lang=en#/History.aspx?lang=en.
(3) http://www.atomium.be/360.aspx.

Over Lapping:

As mentioned in the last two classifications, overlapping may occur between the levels. The followings are examples

- Mimicry of hydrophobic surfaces used in cleaning and gathering fog is morphology mimicry and skin mimicry
- Mimicry of materials that respond unevenly to heat or humidity is material mimicry and in the same time process mimicry.

2.2. Fields of Application in Environmental Architecture:

Biomimicry can be applied to environmental architecture in three fundamental fields (1):

2.2.1 Production of More Appropriate Materials:

Scientists have already produced a self cleaning paint after the lotus flower. This opens the field of hope to produce self-coloring wall claddings that change their colors with the falling sun rays, the same way the butterflies do.

a. Making a Self Cleaning Paints after Lotus Leaves:

Beads of water form on the surface of a lotus leaf, and then the beads roll off the surface and take small particles of dirt with them, as shown in Figs. (2-1) and (2-2)

The natural self-cleaning properties of the leaf are produced by a microscopically rough and super hydrophobic surface, which was discovered by the botanist “Wilhelm Barthlot” (2) and “Cristoph Neinhuis”, at the University of Bonn (3).

“A surface which the Lotus-effect is super hydrophobic, expressed by a contact angle larger than 150º. Due to this superhydrophobicity, water tends to roll off the surface, ----- and cleans the surface of a contamination in its way (4)*.”*

The new surface technology also reduces the risk of attack by microorganisms. Algae and fungal spores are either washed off or are unable to survive on a dry and dirt-free exterior.

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(1) Koelman, O., "Biomimetic Buildings: Understanding & Applying the Lessons of Nature”.
(2) Lai, S., "Mimicking Nature: Physical Basis and Artificial Synthesis of the Lotus-Effect", p.3.
(3) Williams, H., “Towards Biomimetic Architecture”.
(4) Lai, S., “ibid”, P.12.

Figure (2-1)
Beads on a Lotus Leave
(www.creativeresourcelab.com)

Figure (2-2) A Droplet Takes up the Dust Covering a Lotus Leaf.
(www.botanik.unibonn.de/system/lotus/en/prinzip_html.html)

According to Bhushan , self cleaning surfaces can be produced by using roughness combined with hydrophobic coatings (1).

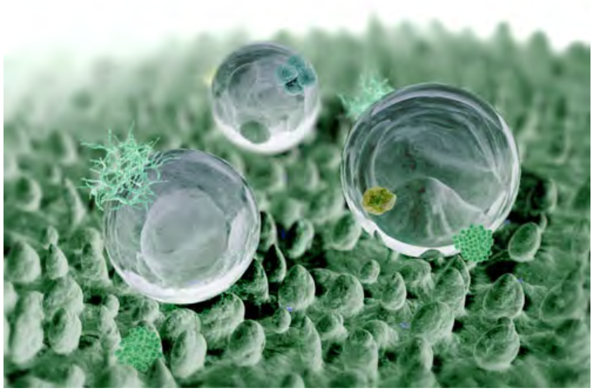

Figure (2-3) Lotus Effect.
(photo by william thielicke)
(www.designboom.com/contemporary/biomimicry.html)

> *"When a surface has many tiny bumps, and these bumps are formed from a water-repellent substance, water drops "sit" on top of the bumps, cushioned by the air in the space beneath them. The area of contact between the water drop and the surface is dramatically reduced by these bumps (2)."*

Figs (2-4) and (2-5) illustrate the concept.

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(1) Bhushan, B., "Micro-, Nano- and Hierarchical Structures for Superhydrophobicity, Self-Cleaning and Low Adhesion".

(2) Forbes, P., "The Gecko's Foot", p. 35.

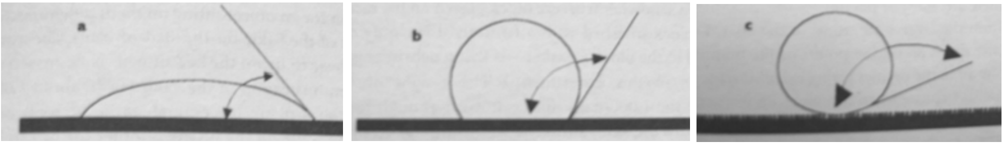

Figure (2-4) Typical Contact Angle of Water on:

a- A water loving (hydrophilic) surface-less than 30º
b- A water-repelling (hydrophobic) surface-greater than 90º
c- A Lotus Effect® (Super hydrophobic)surface-greater than 150 º
(Forbes, 2006)

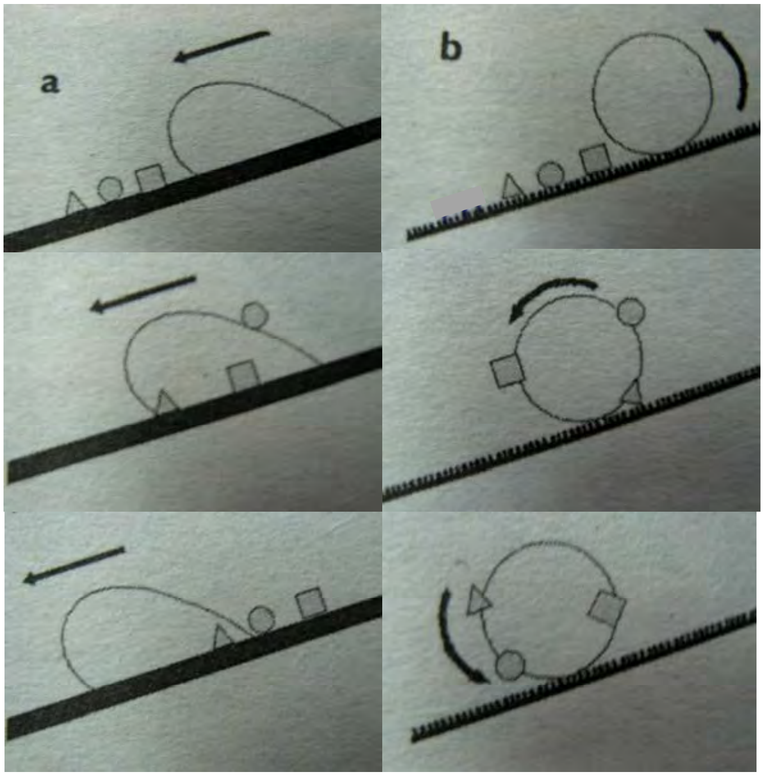

Figure (2-5)
Behavior of Dirt Particles on Ordinary and 'Lotus-Effect' Surfaces.

a- On an ordinary surface, dirt particles have strong affinity for the surface than they do for water; they remain after rainwater washes over them.
b- On a Lotus-Effect surface, dirt 'sits' on top of the micro-bumps and is easily carried off by rainwater.
(Forbes, 2006)

This phenomenon helped the scientists to produce a new paint "Lotusan" that keep building facades clean (1).

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(1) www.asknature.org/product/6b8342fc3e784201e4950dbd80510455

A self cleaning glass, 'Pilkington Activ ^{TM}' was also produced (1). This may give further inspiration to produce pre-fabricated self-cleaning exterior wall cladding panels.

b. Making Self-Coloring Wall Panels after Butterflies and Sea Shells:

The iridescent colors we see in a soap bubble are produced by interference, so are the metallic colors found in some insects. These colors are produced by an object's surface structure, rather than by incorporated pigment molecules and they are often referred to as "structural colors."

When an incoming ray of light strikes the outer surface of a bubble, part of the light ray is immediately reflected, while the other part is transmitted into the soap film. Fig. (2-6)

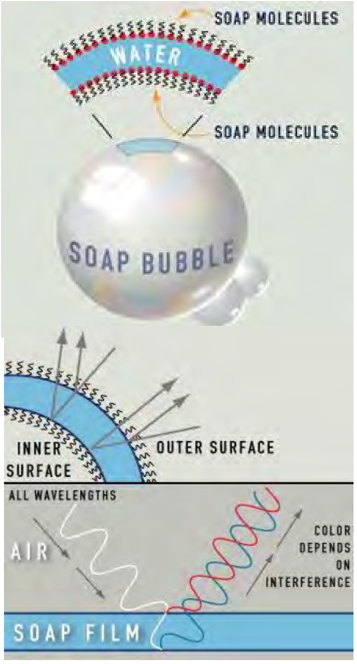

Figure (2-6) Soap Bubble Thin Film the Cause of Iridescent Colors
(www.webexhibits.org)

After reaching the inner surface of the film, this transmitted light ray is reflected back toward the outer surface. When it leaves the bubble, it travels in the same direction as the ray that was immediately reflected and is, therefore, parallel to that ray (2).

If the wavelengths of the two reflected rays are "in phase", they will enhance each other. This is called "constructive interference" and it produces iridescent color.

But If the two rays of light are reflected back so that their wavelengths are "out of phase" with each other, the second ray will partly cancel out the reflection of the first ray. This is called "destructive interference" and the result is a reduction in color intensity, as shown in figs. (2-7) and (2-8).

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(1) Williams, H., "Towards Biomimetic Architecture".
(2) www.webexhibits.org/causesofcolor/15.html

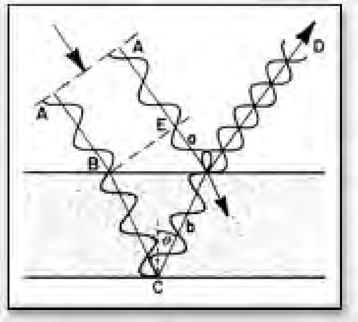

Figure (2-7): Interference of Light Beams Reflected from the Front and Back Surfaces of a Thin Parallel Film
(www.webexhibits.org/causesofcolor/15.html)

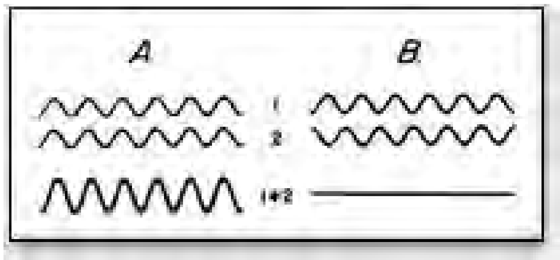

Figure (2-8): Constructive and Destructive Interference.
Light waves 1 and 2 produce constructive reinforcement if they are in phase (A) or destructive cancellation if they are out of phase (B).
(www.webexhibits.org/causesofcolor/15.html)

In the sea shell, waves of light are slowed down by the thin layers of chitin, which are layers on top of each other. If the wavelength of light is refracted (slowed down) by the change in traveling medium, from air to chitin, some wavelengths of light are reflected off the bottom surface of the thin film, and placed back in phase with light that has not penetrated the thin film, but reflected off the top surface (1). Fig. (2-9) shows a cross section in the sea shell.

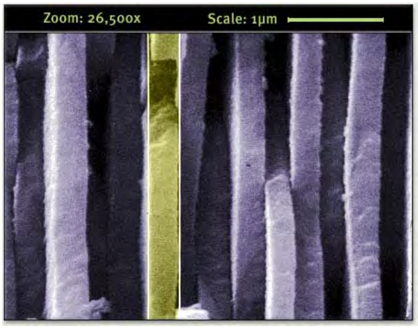

Figure (2-9):
Constructive Cross Section of a Piece of a Sea Shell. It is Made of Chitin. One Layer is Highlighted in Yellow.
(www.webexhibits.org)

Structural color is also found in many insects, such as butterflies, due to the presence of scales. The wing scales have hierarchical structure at various length scales (2), as shown in fig. (2-10). Blue and green shades are provided from light scattered off the hierarchical structure on the wing (3). Bhushan also states that textile fabric, paints and cosmetics have been developed based on the surface of butterflies. (4)

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(1) http://www.optics.rochester.edu/workgroups/cml/me111/sp98-projects/boris/
(2) Bhushan, B., “Biomimetics: Lessons from Nature-an Overview".
(3) Whereas red and yellow wing colors are provided by colored pigments.
More Images are viewed in the appendix, at p. 243.
(4) Bhushan, B., “ibid”.

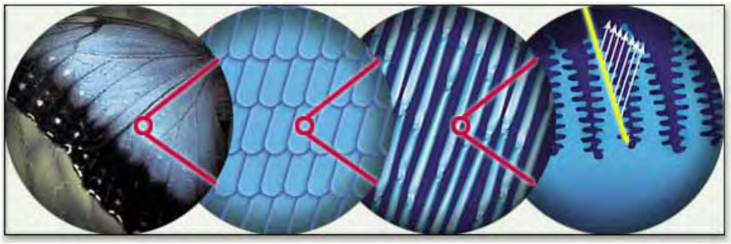

Figure (2-10): Butterfly Wing Scales
(www.webexhibits.org/causesofcolor/15A.html)

According to this, it could be soon possible to use pre fabricated self coloring exterior wall panels, as it is seen that using them would eliminate all the painting and repainting requirements and cons.

2.2.2 Fulfilling Functional Designs, by Following Natural Processes:

a. Heating Strategies in Ant nest:

The wood ants (Formica rufa) have several strategies to worm their nests:

1. The surface has numerous holes which serve as entrances and ventilation holes; at night and in cold weather the ants plug the holes to keep heat in.
2. The workers also keep the slope of the nest at the right angle to obtain maximum amount of solar heat, where the southern side of the nest is flatter to present a greater surface area to the midday sun (1).

Figure (2-11) wood Ant (Formica Rufa) Nest
(www.commons.wikimedia.org/wiki/File:Formica_rufa_nest.jpg)

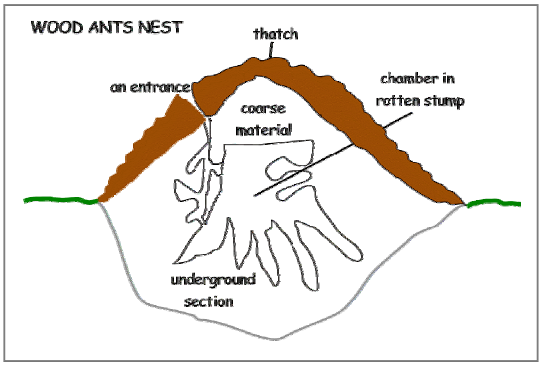

Figure (2-12) Section of Wood Ant Nest.
(http://www.norseywood.org.uk/wood/fauna-and-flora/wood-ant-nest.htm)

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(1) www.treesforlife.org.uk/tfl.woodants.html

This may inspire architects to choose the slope angles of their building consciously, as applied in City Hall in London (1), where leaning back towards the south provides shading.

3. The ants bring extra warmth into their nests as live heaters by basking in the sun in large numbers and taking the heat energy collected in their bodies into the nest (2).

b.Cooling strategy in ant body:

When a little ant moves from a shaded area to a suny area, little air-scoops on its side automatically switch on. A mist of cooling water vapor puffs upward from them. That keeps the ant's temperature down (2).

Figure (2-13) Swiss Re Building
(www.biral.com/articles/swissre.pdf)

This inspires the strategy of windows that automatically opens accordig to changing temperature, like those in Swiss Re building, shown in Fig. (2-13).

The building achieves this function via a set of sensors as follows:

a. Six ultrasonic anemometers for three dimensional wind speed and direction monitoring
b. A multiple parameter sensor positioned at the apex provides control values for brightness, temperature and relative humidity readings.
c. Four pyranometers (3) to monitor the sunshine intensity.
d. Five equally spaced monitors to automate the control of window and ventilation openings (4).

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(1) The building will be illustrated at p. 182.
(2) www.asknature.org.
(3) Pyranometers measure broadband solar irradiance on a planar surface and is a sensor that is designed to measure the solar radiation flux density (in watts per meter square) from a field of view of 180 degrees.
(4) Bristol Industrial and Research Associates Limited, at www.biral.com/articles/swissre.pdf.

2.2.3 Preservation of Resources, Rather Than Draining Them, by Utilizing the Biomimicry Principles of Zero Waste:

a) Cleaning Water in Living Machines after Wetland:

The Living Machine purifies used water, by mimicking the natural purification processes of ponds and marshes (1).

b) Geothermal Heating and Cooling:

Closed loop system, an ecosystem property, is clearly seen in the way in which water is cooled and heated in 2211 west forth building (2). Ground source heat pump uses "heat transfer" fluid to take heat from the ground, or displace heat to ground as needed. This heats and cools the penthouses and commercial levels, and heats water for the entire project.

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(1) Previously detailed at p. 47.
(2) Previously illustrated at p. 19.

Summary:

Chapter two deals with Biomimicry as an approach to the Architectural Environmental Design.

It started with viewing classifications of biomimicry levels. In this context, a comparison between two classifications was held, and two new classifications resulted, general and architectural.

Then, the chapter views the fields in which the new discipline can serve environmental architecture.

Conclusions:

1. The levels of biomimicry can be classified in the following classification, taking into account that nature works in systems:
    a. Three general levels
        1) Form or Structure level
        2) Behavior or process level
        3) Ecosystem level.
    b. Nine Architectural levels:
        1) Concept
        2) Process
        3) Morphology
        4) Form
        5) Structure.
        6) Skin.
        7) Material.
        8) Expression.
        9) Symbolism.

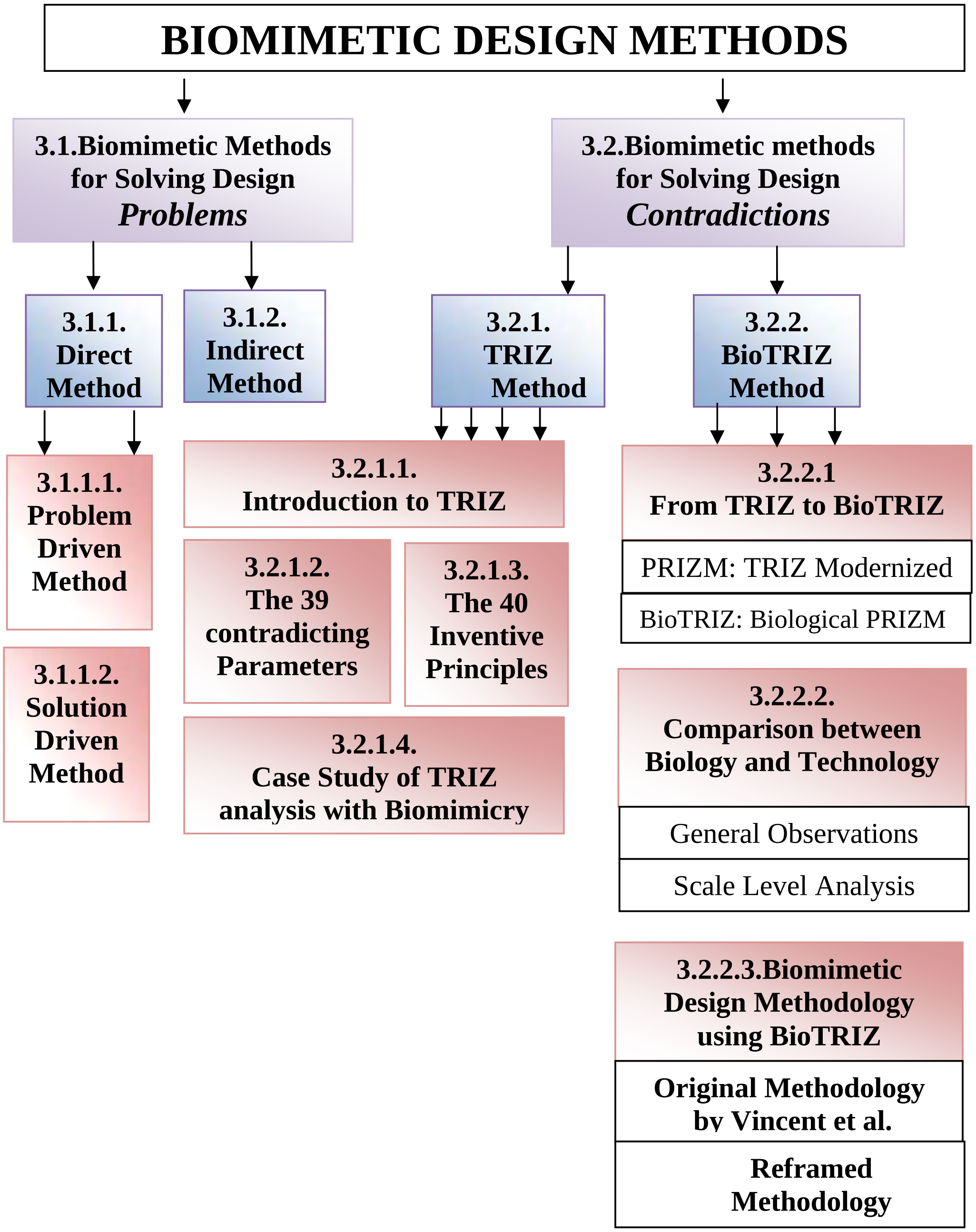
2. The discipline of Biomimicry can serve environmental architecture in the following fields:
    a. Production of more appropriate materials
    b. Fulfilling functional designs, by following natural processes.
    c. Preservation of resources, rather than draining them.
3. Design of skins in nature, widely depends on information transforming and response. That is what is called “Responsive skin”.

Chapter 3

BIOMIMETIC DESIGN METHODS

Creativity Can be Managed
…. anonymous saying

Chapter 3



BIOMIMETIC DESIGN METHODS

- 3.1.Biomimetic Methods for Solving Design *Problems*
  - 3.1.1. Direct Method
    - 3.1.1.1. Problem Driven Method
    - 3.1.1.2. Solution Driven Method
  - 3.1.2. Indirect Method
- 3.2.Biomimetic methods for Solving Design *Contradictions*
  - 3.2.1. TRIZ Method
    - 3.2.1.1. Introduction to TRIZ
    - 3.2.1.2. The 39 contradicting Parameters
    - 3.2.1.3. The 40 Inventive Principles
    - 3.2.1.4. Case Study of TRIZ analysis with Biomimicry
  - 3.2.2. BioTRIZ Method
    - 3.2.2.1 From TRIZ to BioTRIZ
      - PRIZM: TRIZ Modernized
      - BioTRIZ: Biological PRIZM
    - 3.2.2.2. Comparison between Biology and Technology
      - General Observations
      - Scale Level Analysis
    - 3.2.2.3.Biomimetic Design Methodology using BioTRIZ
      - Original Methodology by Vincent et al.
      - Reframed Methodology

Chapter 3

BIOMIMETIC DESIGN METHODS

Chapter Three

Biomimetic Design Methods

It might be undisputed that nature has much to learn from, but the problem lies in the knowledge of how to apply the ingenuity of nature in a practical way to enhance our products, buildings and way of life.

Many efforts have been made to figure out methods that can be used to design and build biomimetic products, and buildings.

This chapter will view these methods; in an attempt to present at least one methodology that architects could follow in their way to design adaptable buildings.

Beside the Biomimetic methods for Solving Design Problems, Two methods of solving design contradictions will be viewed. Those are “TRIZ”, a systematic method for solving engineering contradictions invented in the 1970s, and "BioTRIZ", a method developed in the last few years merging TRIZ with Biomimetics.

Those two methods will be viewed to find out if they could also be used to reach biomimetic architectural solutions.

3.1. Biomimetics methods for Solving Design Problems.

Faludi states that there are two basic methods for Biomimetic design, direct and indirect methods (1):

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(1) Faludi, J., "Biomimicry for Green Design (A How to)”.

3.1.1. Direct Method:

The designer follows systematic steps to reach a biomimetic solution to a specific problem.

For this method, two different approaches will be viewed:
Design looking to Biology, and Biology influencing design (1).
Both will be viewed as follows:

3.1.1.1.Design looking to Biology (Problem-Driven Biologically inspired design process):

Designers begin by defining a human need or design problem, and then look to the ways that other organisms use to solve the same problem.

An example of this approach is Daimler Chrysler's bionic car, where the designer aimed at creating a large volume car with small wheels; the design was based on the box fish (Ostracion meleagris) that has an aerodyamic shape as shown in Fig. (3-1)

So the designer here started with a specific problem (Problem-Driven), for which he tried to find a solution by searching in nature (looking to biology).

Figure (3-1): Daimler Chrysler's Bionic Car after Box Fish.
(Zari, 2007)

Two attempts were found to draw a methodology for the problem-driven design process. First by Helms et al. and the second by Carl Hastrich.

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(1) Pedersen Zari, M., “Biomimetic Approaches to Architectural Design for Increased Sustainability”, and:
Helms, M. et al., and Yen, J., “Problem-Driven and Solution-Based Design: Twin Processes of Biologically Inspired Design”.

a) First Methodology (Presented by Helms et al.,(1)):

- **Step 1: Problem definition:**

  Define the problem as a function

- **Step 2: Problem reframing:**

  Make a question like "How does the biological solution accomplish this function?"

- **Step 3: Biological solution search:**

  Use search tecniques described in table (3-1).

Table: (3-1): Biological Solution Search Techniques. (Helms et al., 2008)

Search Technique	Technique Description
Change Constraints	If the problem is narrowly defined, such as "keeping cool", change the constraints to increase the search space, for instance to "thermoregulation".
Champion Adapters	Find an organism or a system that survives in the most extreme case of the problem. For instance, for "keeping cool", look for animals that survive in dessert or equatorial climates.
Multi-Functionality	Find organisms or systems with single solutions that solve multiple problems simultaneously.

- **Step 4: Biological solution definition:**

  Identify the structure or mechanism found in the organism or ecosystem that is responsible on achieving the function required, For example, the abalone shell is hard, light weight and resists impact because of the complex interactions of its composite materials.

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(1) Helms, M. et al., and Yen, J., "Problem-Driven and Solution-Based Design: Twin Processes of Biologically Inspired Design".

- **Step 5: Principle extraction:**

Now after a solution was well understood, extract the important principles into a "solution-neutral form" removing as many constraints as possible.

For example, in describing the principles of the abalone shell, don’t say: "*Interactions between flexible protenis and hexagonal calcium carbonate deposits"*, because this may constrain design thinking to proteins, calcium carbonate, and hexagons. Instead say: "*Tightly coupled composite material formation with alternating flexible and rigid structures for resisting impact."*

- **Step 6: Principle application:**

Translate the principle into the new domain.This translation involves interpretation from one domain space (biology) to another (Egineering), by introducing new constraints.
For example, In the case of producing a bullet proof vest, new weight, flexibility and manufacturig process criteria will be added.
This step often creates new sub-problems, which desigers frequently solves with new biologically inspired solutions.

This is why it is claimed that the pattern of problem-driven biologically inspired design is non-linear and dynamic, where output from later stages frequently influences previous stages, providing iterative feedback and refinement loops.

This is clearly seen in the second attempt for the problem-driven design process, known as "Biomimicry design spiral".

b) Second Methodology: Biomimicry Design Spiral (Presented by Carl Hastrich) (1):

- **Step 1: Identify**
    - Develop a Design Brief of the human need.
    - Ask: “What do you want your design to do?” –instead of “What do you want to design?”, and “why?”
    - Continue to ask why until you get to the bottom of the problem.
    - Ask further questions to Define the specifics of the problem:
        - Who: Who is involved with the problem and who will be involved with the solution?
        - Where: Where is the problem, where will the solution be applied?

- **Step 2: Translate:**
    - Translate the design brief into biological terms, or “Biologize” the question
    - Identify functions
    - How does Nature do this? How does nature not do this?
    - Define the Habitat, the climate, nutrient and social conditions
    - How does Nature achieve this function in this environment?

- **Step 3: Discover:**
    - Find the best Natural Models to answer your questions.
    - Think in both ways Literal and Metaphorical.

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(1) Biomimicry Newsletter, (Mar. 2006), Vol. 4, Issue 1.

  - Find champion adapters by asking “whose survival depends on this?”
  - Look to the extremes of the habitat
  - Open discussions with Biologists and specialists in the field
  - Create taxonomy (1) of life’s strategies, and from this list, choose the most promising strategies for emulation.

- **Step 4: Emulate:**
  - Develop solutions based on the Biological Models.
  - Find out details of the morphology or process.
  - Understand scale effects.
  - Consider influencing factors on the effectiveness of the form for the organism.

- **Step 5: Evaluate:**
  - Review solutions against Life’s Principles.
  - Take appropriate question from the list below and continue to question your solution:
    - Is the design modular (2)/segmented?
    - Is shape designed to minimize material?
    - Is it optimized rather than maximized?
    - What role does water play?
    - Is the design locally adapted?
    - Does it use free energy?
    - Does the design promote appropriate behaviors by users?
    - Does it use life-friendly materials?

---

(1) Classification of organisms into groups based on similarities of structure or origin etc.
(2) Constructed with standardized units or dimensions allowing flexibility and variety.

    - Is the manufacturing benign?
    - Does the design “create conditions conducive to life”?

  - Identify further ways to improve your design. The questions now are about the refinmet of the concept, Manufacturing, transport...etc.

- **<u>Step 6 (or again 1): Identify</u>**
  - Develop a new Design Brief from questions highlighted by Life’s Principles**.**

Again appears the feedback loop, as the process ends up with new questions aiming at project refinment, these questions lead us to begin new process. The design spiral method is illusrated in Fig. (3-2)

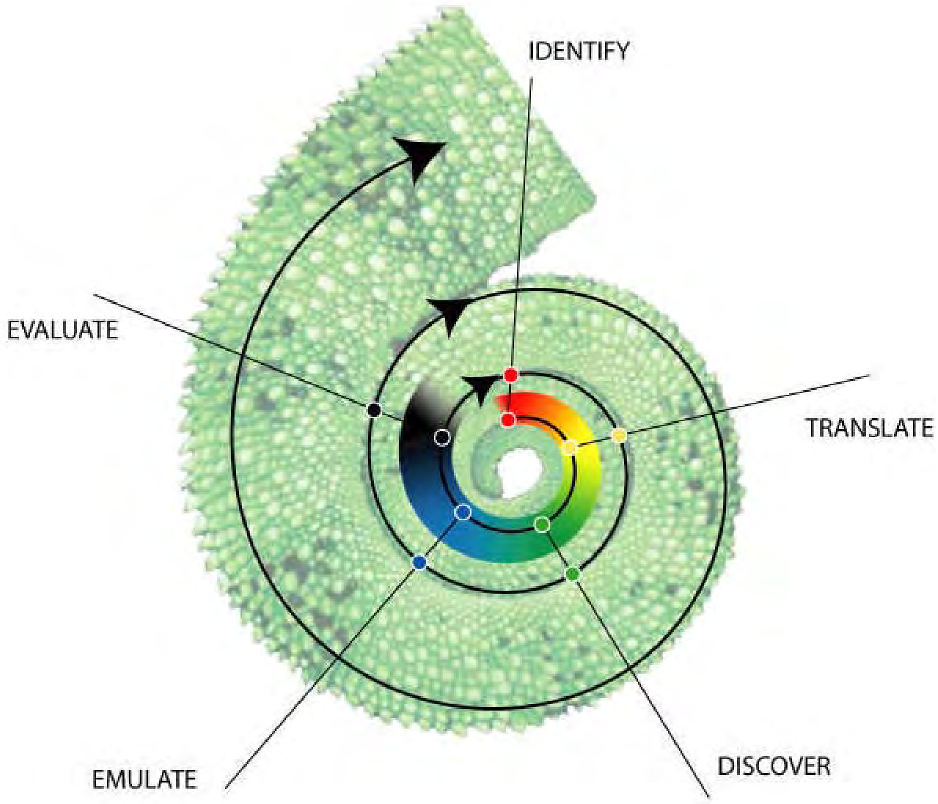

Figure (3-2): Biomimicry Design Spiral.
(Biomimicry News Letter, 2006)

c) Comparison between First and Second methodologies:

Both methodologies are sharing the first three steps, as shown in table (3-2).

- **<u>First step:</u>**

  (Forming a question): What do you want the design to do?

- **<u>Second step:</u>**

  (Forming a question): How does nature do this?

- **<u>Third step:</u>**

  (Search): What is the orgaism that does this?

- **<u>Forth step:</u>**
  - <u>In the first methodology</u>: (Biological solution analysis-Phase one) Find the mechanism that is responsible on achieving the function.
  - <u>In the second methodology</u>: (Developing solution based on Biological solution analysis of morphology, form and any other influencing factors).

  Both methodologies are making analysis for the mechanism responsible on the function required, the morphology, techniques...etc. But while the first methodology is limited to analysing the biological solution, the second methodology starts developing the human solution in this step.

- **<u>Fifth step:</u>**

  <u>In the first methodology</u>: (Biological solution analysis-Phase two): "Termig the biological solution strategy in abstract words"
  <u>In the second methodology</u>: Review the developed human solution

  While the first methodology is still analysing the biological solution, putting the principles found in abstract words, the second methodology is reviewing the human solution that was developed in the previous step to find if it is consistent with life's principles.

- **Last step:**

  In the first methodology: Applying the principle abstracted in the previous step.

  In the second methodology: Identify new problem or in fact, new question based on the review held in the previous step.

  The first methodology came to the applying step at last, while the second is beginning new spiral by identifing new problems to solve.

Although it seems that the second methodology is more comprehensive, in terms that it includes the action of identifing new problems emerging in the last step. But Helms et al., state that even designers use the first methodology also ends up with new sub-problems that lead them to a new process.

The note here is that if there are new sub-problems or questions emerged in the process, then starting new process should be referred to in the methodology. So this is an advantage in the second methodology

According to this, the first methodology will be considered more advanced in biological solution analysis in general and in the fifth step in particular, as extracting Principle in abstract words may end up with accurate human solution.

Table (3-2): Comparison between the Two Methodologies of the Problem-Driven Design Process:

	Helms et al.	Carl Hastrich	Comparison
Step 1	**Problem definition** Define the problem as a function	**identify** Ask What do you want your Design to do?	**The same:** Form the question
Step 2	**Problem reframing** Ask: How does the biological solution accomplish this function?	**Traslate** Ask: How does Nature do this?	**The same:** Biologize the question
Step 3	**Biological solution search**	**Discover** Discover Biological Models to answer your questions	**The same:** Find the biological solution "organism or ecosystem property"
Step 4	**Biological solution definition** Identify the mechanism that accomplish the function	**Emulate** Develop solutions based on the Biological Models. Find out details of the Morphology or process	**First:** Biological solution analysis (phase1):"Find how the organism accomplishes the fuction." **Second:** Develop solution based on Biological solution analysis
Step 5	**Principle extraction** Put important priciples in a "solution-neutral form"	**Evaluate** Review solutions against Life’s Principles	**First:** Biological solution analysis (phase2):"Terming the solution strategy." **Second:** review the solution
Step 6	**Principle application** Apply by introdusing new constraints	**Identify** Develop a new Design Brief from questions highlighted by Life’s Principles.	**First:** apply with new sub-problems emerged and solved with new process. **Second:** Once more, ask: What do I want my design to do?

d) Resulted Problem Driven Methodology:

From the previous two methodologies, a suggested methodology can be formed:

1-Form a question:

Ask: "What do I want my design to do?”

2-Biologize the question:

Ask: "How does nature do this in its environment?”

3-Find the model:

Search for and choose the best organism that solves your problem. The champion adapter is the organism whom survival depend on answering this question.

4-Anlyze the model:

Study the michaism and/or form that enable the organism to accomplish the function, consider the morphology, the scale and any other influencing factors.

5-Term the strategy:

Put the principles you've learned in the previous step in abstract words.

6-Design solution

Design your own solution based on the abstract principle you have formed.

7-Review solution

Check if your solution is:

- Completely able to answer your question or there are new sub-problems need to be solved.
- Consistent with life principles or not.

8-Form new questions

According to your answers in the previous step, Form new question: "What do I want my design to do?

3.1.1.2.Biology Influencing Design (Solution-Driven Biologically inspired Design Process)(1):

Designers here start with a particular biological solution in mind. They begin by identifying a particular characteristic, behavior or function in an organism or ecosystem and translating that into human design.

An example is the observation of lotus flower that emerges clean from swampy waters, this observation led to the design of the self cleaning paint, "Lotusan" (2) shown in Fig. (3-3).

"Velcro" is another example. The observation of how the seed of the burdock plant had stuck to the fur of the dog led to the design of that famous hook and loop fastener (3) shown in Fig. (3-4).

Figure (3-3): Model of Solution-Driven Design Process:
Lotusan Paint after Lotus Flower
(Zari, 2007)

Figure (3-4): Model of Solution-Driven Design Process:
Velcro after the Burdock Seed.
(www.en.wikipedia.org)

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(1) Helms, M. et al., and Yen, J., "Problem-Driven and Solution-Based Design: Twin Processes of Biologically Inspired Design".
(2) Previously mentioned at p. 70.
(3) Previously mentioned in the introduction, p. (XXVII).

One methodology was found to be applied for this process:

Step 1: Biological Solution Identification:

The design process begins with a particular biological solution in mind.

Step 2: Define the Biological Solution:

Identify the structure or mechanism found in the biological solution that is responsible on achieving the function required.

(Check step 4 in method 1 of "Design looking to biology").

Step 3: Principle Extraction:

Extract important principles into a "solution-neutral form" removing as many constraints as possible.

(Check step 5 in method 1 of "Design looking to biology").

Step 4: Reframe the Solution:

"Humanize” the Problem-Solution pair.

The solution and applicable principles must be reframed in a context useful to human engineers.

Step 5: Problem Search:

Find an existing or define a new problem to which the solution applies.

Step 6: Problem Definition.

Step 7: Principle Application:

Apply the relevant solution principles to the new problem.

3.1.2. Indirect Method (1):

No previously determined steps are set to the designer to follow, instead, he goes through his own design experience taking the natural design principles in mind, trying to achieve as many of them as possible in his product.

Natural designs (2):

1. Run on the sun and other natural sources of energy.
2. Use only the energy and resources that it needs.
3. Fit form to function efficiently.
4. Recycle everything.
5. Reward cooperation and makes symbiotic relationships work.
6. Develop diversity of possibilities.
7. Require local expertise.
8. Avoid excesses and overbuilding.
9. Tap the power of limits.
10. Depend on Network creation instead of linearity.
11. Depend on Organizing Fractally.
12. Rely upon swarm intelligence.

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(1) Faludi, J., "Biomimicry for Green Design (A How to)".

(2) Viewed in detail in chapter one, pp. 4-39, and a comprehensive review of the design principles in nature is illustrated in the appendices, p. 261.

3.2. Biomimetic methods for Solving Design Contradictions

3.2.1. TRIZ Contradiction Matrix:

3.2.1.1. Introduction to TRIZ:

In the context of Biomimetics methods, TRIZ (1) and BioTRIZ methods are always mentioned. This makes the study of both of them essential to find out how architects can make use of them.

TRIZ (pronounced ‘Trreeez’) is a Russian language acronym for ‘Teoriya Resheniya Izobreatatelskikh Zadatch’: ‘The theory of creative problem solving’ or ‘inventive problem solving’ (2). It was invented or perhaps, discovered by a mechanical engineer "Genrich Altshuller".

Altshuller believed that there should be a standard method for problem solving that would be:

1. Systematic.
2. Teachable.
3. Not dependent upon psychological tools like brainstorming (3).

Why Systematic method is important:

To make the difference between the brainstorming and TRIZ method clear, Spain stated that for an actual problem, the solution is hidden by a wall (3), as shown in Fig. (3-5)

In brainstorming, the designer chips away at the wall hoping that one idea will lead to another and eventually the brick drops to make a hole big enough to reveal a solution as shown in Fig. (3-6).

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(1) TRIZ is a collection of tools and techniques (Vencint, 2006). This work will deal only with one tool, the TRIZ Contradiction Matrix.

(2) In Russian: "Теория решения изобретательских задач”.

(3) Spain, E., “TRIZ Uncovering Hidden Treasures”.

Altshuller's beleived that instead of this 'psychological' method, it must be possible to put the problem into an abstract statement that could then be subjected to certain definable processes. Fig. (3-7)

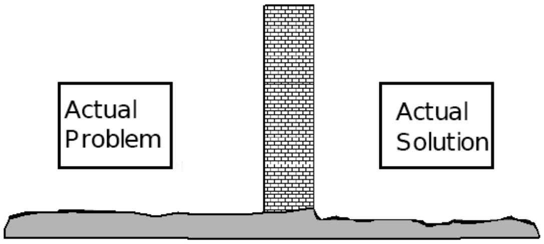

Figure (3-5): Problem and Solution Divided by a Wall.
(Spain, 2003)

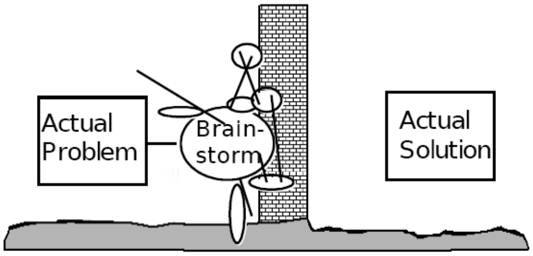

Figure (3-6): Brain-Storming Method.
(Spain, 2003)

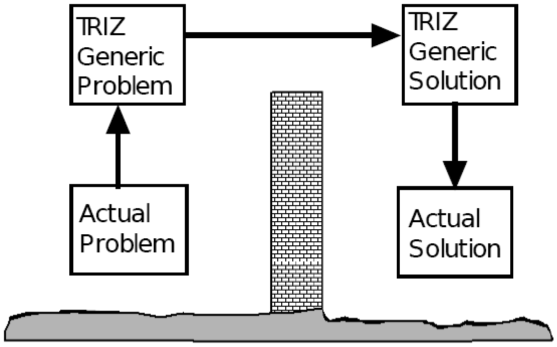

Figure (3-7): Using Abstraction and TRIZ to Solve Problems.
(Spain, 2003)

So, Altshuller's' suggested steps to solve a problem, which are:

1. Abstract your problem from your technology.
2. Use TRIZ processes to see what solutions have already been used in other technologies to solve the same problem.
3. Reach your own specific solution in your technology

Altshuller studied with his colleague about 20000 patents and innovations, and came out with conclusions.

We shouldn't re-invent the wheel.

Very different industries are all solving very similar problems and that by constructing an appropriate framework for knowledge it makes it possible for the expert to see how experts in other fields have solved similar problems, even if, at first sight, those problems do not appear to be the same (1).

3.2.1.2. The 39 Contradicting Parameters

Sometimes when trying to solve a problem by making something stronger, it becomes heavier, when using a different material that makes it more expensive.

These contradictions make the problem seems like a bag of jelly as shown in Fig. (3-8), when improving one parameter, another parameter pulges and gets worce (2). This is called a system conflict.

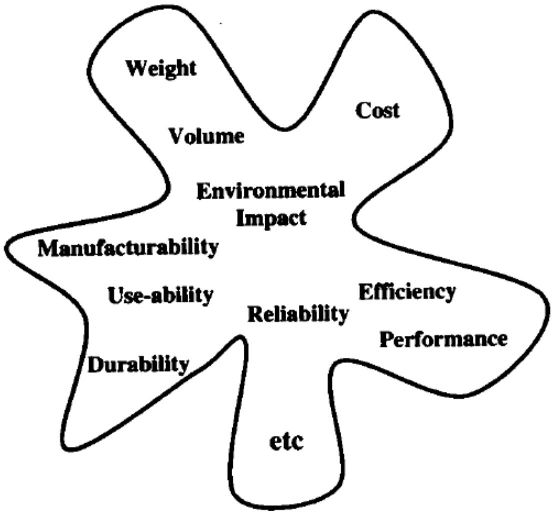

Figure (3-8): A Problem Like a Bag of Jelly.
(Spain, 2003)

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(1) Mann, D., "TRIZ: an Introduction".
(2) Spain, E., “TRIZ Uncovering Hidden Treasures”.

A system conflict is present when:

· the useful action causes simultaneously a harmful effect.

· the introduction of the useful action, or reduction of the harmful action causes deterioration or unacceptable complication of one of the system's parts or of the whole system (1).

Altshuller determined that there are 39 such competing parameters in physical devices.

Here is a list of the competing parameters with a breif definition of each (2):

1. Weight of Moving Object.

2. Weight of Stationary Object: The mass of the subsystem, element, or technique in a gravitational field.

3. Length of a Moving Object.

4. Length of a Stationary Object.

5. Area of a Moving Object.

6. Area of a Stationary Object: The part of a surface occupied by the subsystem.

7. Volume of Moving Object.

8. Volume of Stationary Object: The part of a space, internal or external, occupied by the subsystem.

9. Speed: The velocity of the subsystem.

10. Force (Intensity): Any interaction that can change the subsystem's condition due to the interaction between subsystems.

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(1) Fey, V., and Rivin, E., "System Conflicts or What Makes Some Problems Difficult to Solve".

(2) Savransky, S., "Engineering of Creativity-Introduction to TRIZ Methodology of Inventive Problem Solving".

11. Stress or Pressure: Tension on or inside the subsystem.

12. Shape: The external contours, boundaries that separate the subsystem from the environment or other subsystems.

13. Stability of the Objects Composition: The ability of the subsystem to keep its integrity.

14. Strength: The ability of the subsystem to resist a change in response to force. For example, resistance to breaking.

15. Duration of Action by a Moving Object
16. Duration of action of Stationary Object: The time during which the subsystem can perform useful functions (durability). It can be estimated as the service life.

17. Temperature: The thermal condition of the subsystem.

18. Illumination Intensity: Light flux per unit area.

19. Use of Energy by Moving Object
20. Use of Energy by Stationary Object: to perform a particular function.

21. Power: The time rate of energy usage due to which the subsystem's functions are performed.

22. Loss of Energy: Use of energy (such as heat) that does not contribute to the job being done

23. Loss of Substance: Partial or complete, permanent or temporary loss of some of the subsystem's materials or elements.

24. Loss of Information: Partial or complete, permanent or temporary loss of data or access to data in or by the subsystem.

25. Loss of Time: Time is the duration of an activity. Improving the loss of time means reducing the time taken out of the activity.

26. Quantity of Substance/Matter: The number of the subsystem's materials or elements that might be changed fully or partially, permanently or temporarily.

27. Reliability: The subsystem's ability to perform its intended functions in predictable ways and conditions.

28. Measurement Accuracy: The closeness of the measured value to the actual value of the subsystem parameter.

29. Manufacturing Precision: The closeness of the actual characteristics of the subsystem to the specified or required characteristics that can be achieved during the subsystem production.

30. External harm affects the object: Susceptibility of the subsystem to externally generated harmful effects.

31. Object-generated harmful factors: A harmful effect that is generated by the subsystem as part of its operation within the technique, and that reduces the efficiency or quality of the functioning of the subsystem or whole technique.

32. Ease of Manufacture: The degree of facility, comfort, ease, or effortlessness in manufacturing or fabricating of the subsystem.

33. Ease of Operation: The technique is not convenient if it requires many steps to operate or needs special tools, many highly skilled workers, etc.

34. Ease of Repair: Quality characteristics such as convenience, comfort, simplicity, and time to repair faults, failures, or defects in the subsystem.

35. Adaptability or Versatility: The ability of the subsystem to respond positively to external changes, and the versatility of the subsystem that can be used in multiple ways under a variety of circumstances.

36. System Complexity: The number and diversity of elements and element interrelationships within the subsystem. The user may be an element of the subsystem that increases the complexity. The difficulty of mastering the subsystem is a measure of its complexity.

37. Difficulty of Detecting and Measuring (Complexity of control): Measuring or monitoring the subsystems that are difficult, costly, that require much time and labor to set up and use, that have fuzzy relationships between components, or that have components that interfere with each other, demonstrating “difficult to detect and measure.”

38. Level / Extent of Automation: The ability of the subsystem to perform its functions without human interface.It can be devided ito three levels:

- The lowest level of automation is the use of a manually operated tool.
- The intermediate level is when humans program the tool, observe its operation, and interrupt or reprogram as needed.
- The highest level is when the machine senses the operation needed, programs itself, and monitors its own operations.

39. Productivity: The number of functions or operations performed by the subsystem or whole technique per unit of time.The output per unit of time or the cost per unit of output.

3.2.1.3. The 40 Inventive Principles:

By analysing the patents, Altschuller was able to identify what inventors had done to stop one parameter getting worse at the expense of another. He found out that inventors always use the same strategies to solve the same contradictions. These strategies are called: the ‘40 inventive principles’.

He then drew up a matrix as shown in table (3-3), in which both axes are the same: the 39 competing parameters. **Where a column and row intersected, he placed the ‘inventive principle’ that was used to enable the improvement-on the vertical axis-to be made without making the conflicting parameter, on the horizontal axis, worse.**

Notes on the Mattrix:

- Numbers placed in the cells represent the priciples that were found to be used to solve the contradiction between the parameters in the row and column.
- Attetion should be paid when we pick a parameter, to whether it is an improving or worsening feature, because the priciples are not always the same in both cases.

  For example, IP 2 and IP 4 (1) are used to solve the contradiction between "Area of moving object" and "weight of moving object" when the first is a desired or improving feature, but these principles do not solve the same contradiction when the second is the improving feature, instead principles number 38 and 34 could be used.

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(1) (IP) means Inventive Principle.

The principles are presented here in the following system:

- The principle Name (1. Segment- 2. Take out…….etc.)
- The principle explanations: (A, B, C ...etc.) (1).
- Appliacation on these explanations in architecture field stated by Mann and Catháin (2).
- One 'or more' of the conflicts, that the principle is used to solve, usually picked from the matrix to suit the field of architecture.

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(1) From (www.triz40.com/aff_Principles.htm)

(2) Mann, D., and Catháin, C., "40 Inventive (Architecture) Principles with Examples". (www.triz-journal.com/archives/2001/07/b/index.htm)

Table (3-3) TRIZ Contradiction Matrix : *Copied from (http://www.triz40.com/aff_Matrix.htm)*

			39 Worsening Features																																						
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
			1: Weight of moving object	2: Weight of stationary obj.	3: Length of moving obj.	4: Length of stationary obj.	5: Area of Moving Obj.	6: Area of stationary obj.	7: Volume of moving obj.	8: Volume of stationary obj.	9: Speed	10: Force (Intensity)	11: Stress or pressure	12: Shape	13: Stability of the object	14: Strength	15: Durability of moving obj.	16: Durability of non moving obj.	17: Temperature	18: Illumination intensity	19: Use of energy by moving obj.	20: Use of energy by stationary obj.	21: Power	22: Loss of Energy	23: Loss of substance	24: Loss of Information	25: Loss of Time	26: Quantity of substance	27: Reliability	28: Measurement accuracy	29: Manufacturing precision	30: Object-affected harmful	31: Object-generated harmful	32: Ease of manufacture	33: Ease of operation	34: Ease of repair	35: Adaptability or versatility	36: Device complexity	37: Difficulty of detecting	38: Extent of automation	39: Productivity
39 IMPROVING FEATURES	1	1: Weight of moving object	*	-	15 8 29 34	-	29 17 38 34	-	29 2 40 28	-	2 8 15 38	8 10 18 37	10 36 37 40	10 14 35 40	1 35 19 39	28 27 18 40	5 34 31 35	-	6 29 4 38	19 1 32	35 12 34 31	-	12 36 18 31	6 2 34 19	5 35 3 31	10 24 35	10 35 20 28	3 26 18 31	1 3 11 27	28 27 35 26	28 35 26 18	22 21 18 27	22 35 31 39	27 28 1 36	35 3 2 24	2 27 28 11	29 5 15 8	26 30 36 34	28 29 26 32	26 35 18 19	35 3 24 37
	2	2: Weight of stationary object	-	*	-	10 1 29 35	-	35 30 13 2	-	5 35 14 2	-	8 10 19 35	13 29 10 18	13 10 29 14	26 39 1 40	28 2 10 27	-	2 27 19 6	28 19 32 22	19 32 35	-	18 19 28 1	15 19 18 22	18 19 28 15	5 8 13 30	10 15 35	10 20 35 26	19 6 18 26	10 28 8 3	18 26 28	10 1 35 17	2 19 22 37	35 22 1 39	28 1 9	6 13 1 32	2 27 28 11	19 15 29	1 10 26 39	25 28 17 15	2 26 35	1 28 15 35
	3	3: Length of moving object	8 15 29 34	-	*	-	15 17 4	-	7 17 4 35	-	13 4 8	17 10 4	1 8 35	1 8 10 29	1 8 15 34	8 35 29 34	19	-	10 15 19	32	8 35 24	-	1 35	7 2 35 39	4 29 23 10	1 24	15 2 29	29 35	10 14 29 40	28 32 4	10 28 29 37	1 15 17 24	17 15	1 29 17	15 29 35 4	1 28 10	14 15 1 16	1 19 26 24	35 1 26 24	17 24 26 16	14 4 28 29
	4	4: Length of stationary obj.	-	35 28 40 29	-	*	-	17 7 10 40	-	35 8 2 14	-	28 10	1 14 35	13 14 15 7	39 37 35	15 14 28 26	-	1 10 35	3 35 38 18	3 25	-	-	12 8	6 28	10 28 24 35	24 26	30 29 14	-	15 29 28	32 28 3	2 32 10	1 18	-	15 17 27	2 25	3	1 35	1 26	26	-	30 14 7 26
	5	5: Area of Moving Object	2 17 29 4	-	14 15 18 4	-	*	-	7 14 17 4	-	29 30 4 34	19 30 35 2	10 15 36 28	5 34 29 4	11 2 13 39	3 15 40 14	6 3	-	2 15 16	15 32 19 13	19 32	-	19 10 32 18	15 17 30 26	10 35 2 39	30 26	26 4	29 30 6 13	29 9	26 28 32 3	2 32	22 33 28 1	17 2 18 39	13 1 26 24	15 17 13 16	15 13 10 1	15 30	14 1 13	2 36 26 18	14 30 28 23	10 26 34 2
	6	6: Area of stationary object	-	30 2 14 18	-	26 7 9 39	-	*	-	-	-	1 18 35 36	10 15 36 37	-	2 38	40	-	2 10 19 30	35 39 38	-	-	-	17 32	17 7 30	10 14 18 39	30 16	10 35 4 18	2 18 40 4	32 35 40 4	26 28 32 3	2 29 18 36	27 2 39 35	22 1 40	40 16	16 4	16	15 16	1 18 36	2 35 30 18	23	10 15 17 7
	7	7: Volume of moving object	2 26 29 40	-	1 7 4 35	-	1 7 4 17	-	*	-	29 4 38 34	15 35 36 37	6 35 36 37	1 15 29 4	28 10 1 39	9 14 15 7	6 35 4	-	34 39 10 18	2 13 10	35	-	35 6 13 18	7 15 13 16	36 39 34 10	2 22	2 6 34 10	29 30 7	14 1 40 11	25 26 28	25 28 2 16	22 21 27 35	17 2 40 1	29 1 40	15 13 30 12	10	15 29	26 1	29 26 4	35 34 16 24	10 6 2 34
	8	8: Volume of stationary obj.	-	35 10 19 14	19 14	35 8 2 14	-	-	-	*	-	2 18 37	24 35	7 2 35	34 28 35 40	9 14 17 15	-	35 34 38	35 6 4	-	-	-	30 6	-	10 39 35 34	-	35 16 32 18	35 3	2 35 16	-	35 10 25	34 39 19 27	30 18 35 4	35	-	1	-	1 31	2 17 26	-	35 37 10 2
	9	9: Speed	2 28 13 38	-	13 14 8	-	29 30 34	-	7 29 34	-	*	13 28 15 19	6 18 38 40	35 15 18 34	28 33 1 18	8 3 26 14	3 19 35 5	-	28 30 36 2	10 13 19	8 15 35 38	-	19 35 38 2	14 20 19 35	10 13 28 38	13 26	-	10 19 29 38	11 35 27 28	28 32 1 24	10 28 32 25	1 28 35 23	2 24 35 21	35 13 8 1	32 28 13 12	34 2 28 27	15 10 26	10 28 4 34	3 34 27 16	10 18	-
	10	10: Force (Intensity)	8 1 37 18	18 13 1 28	17 19 9 36	28 10	19 10 15	1 18 36 37	15 9 12 37	2 36 18 37	13 28 15 12	*	18 21 11	10 35 40 34	35 10 21	35 10 14 27	19 2	-	35 10 21	-	19 17 10	1 16 36 37	19 35 18 37	14 15	8 35 40 5	-	10 37 36	14 29 18 36	3 35 13 21	35 10 23 24	28 29 37 36	1 35 40 18	13 3 36 24	15 37 18 1	1 28 3 25	15 1 11	15 17 18 20	26 35 10 18	36 37 10 19	2 35	3 28 35 37
	11	11: Stress or pressure	10 36 37 40	13 29 10 18	35 10 36	35 1 14 16	10 15 36 28	10 15 36 37	6 35 10	35 24	6 35 36	36 35 21	*	35 4 15 10	35 33 2 40	9 18 3 40	19 3 27	-	35 39 19 2	-	14 24 10 37	-	10 35 14	2 36 25	10 36 3 37	-	37 36 4	10 14 36	10 13 19 35	6 28 25	3 35	22 2 37	2 33 27 18	1 35 16	11	2	35	19 1 35	2 36 37	35 24	10 14 35 37
	12	12: Shape	8 10 29 40	15 10 26 3	29 34 5 4	13 14 10 7	5 34 4 10	-	14 4 15 22	7 2 35	35 15 34 18	35 10 37 40	34 15 10 14	*	33 1 18 4	30 14 10 40	14 26 9 25	-	22 14 19 32	13 15 32	2 6 34 14	-	4 6 2	14	35 29 3 5	-	14 10 34 17	36 22	10 40 16	28 32 1	32 30 40	22 1 2 35	35 1	1 32 17 28	32 15 26	2 13 1	1 15 29	16 29 1 28	15 13 39	15 1 32	17 26 34 10
	13	13: Stability of the object	21 35 2 39	26 39 1 40	13 15 1 28	37	2 11 13	39	28 10 19 39	34 28 35 40	33 15 28 18	10 35 21 16	2 35 40	22 1 18 4	*	17 9 15	13 27 10 35	39 3 35 23	35 1 32	32 3 27 16	13 19	27 4 29 18	32 35 27 31	14 2 39 6	2 14 30 40	-	35 27	15 32 35	-	13	18	35 24 30 18	35 40 27 39	35 19	32 35 30	2 35 10 16	35 30 34 2	2 35 22 26	35 22 39 23	1 8 35	23 35 40 3
	14	14: Strength	1 8 40 15	40 26 27 1	1 15 8 35	15 14 28 26	3 34 40 29	9 40 28	10 15 14 7	9 14 17 15	8 13 26 14	10 18 3 14	10 3 18 40	10 30 35 40	13 17 35	*	27 3 26	-	30 10 40	35 19	19 35 10	35	10 26 35 28	35	35 28 31 40	-	29 3 28 10	29 10 27	11 3	3 27 16	3 27	18 35 37 1	15 35 22 2	11 3 10 32	32 40 25 2	27 11 3	15 3 32	2 13 25 28	27 3 15 40	15	29 35 10 14
	15	15: Durability of moving obj.	19 5 34 31	-	2 19 9	-	3 17 19	-	10 2 19 30	-	3 35 5	19 2 16	19 3 27	14 26 28 25	13 3 35	27 3 10	*	-	19 35 39	2 19 4 35	28 6 35 18	-	19 10 35 38	-	28 27 3 18	10	20 10 28 18	3 35 10 40	11 2 13	3	3 27 16 40	22 15 33 28	21 39 16 22	27 1 4	12 27	29 10 27	1 35 13	10 4 29 15	19 29 39 35	6 10	35 17 14 19
	16	16: Durability of non moving obj.	-	6 27 19 16	-	1 40 35	-	-	-	35 34 38	-	-	-	-	39 3 35 23	-	-	*	19 18 36 40	-	-	-	16	-	27 16 18 38	10	28 20 10 16	3 35 31	34 27 6 40	10 26 24	-	17 1 40 33	22	35 10	1	1	2	-	25 34 6 35	1	20 10 16 38
	17	17: Temperature	36 22 6 38	22 35 32	15 19 9	15 19 9	3 35 39 18	35 38	34 39 40 18	35 6 4	2 28 36 30	35 10 3 21	35 39 19 2	14 22 19 32	1 35 32	10 30 22 40	19 13 39	19 18 36 40	*	32 30 21 16	19 15 3 17	-	2 14 17 25	21 17 35 38	21 36 29 31	-	35 28 21 18	3 17 30 39	19 35 3 10	32 19 24	24	22 33 35 2	22 35 2 24	26 27	26 27	4 10 16	2 18 27	2 17 16	3 27 35 31	26 2 19 16	15 28 35
	18	18: Illumination intensity	19 1 32	2 35 32	19 32 16	-	19 32 26	-	2 13 10	-	10 13 19	26 19 6	-	32 30	32 3 27	35 19	2 19 6	-	32 35 19	*	32 1 19	32 35 1 15	32	13 16 1 6	13 1	1 6	19 1 26 17	1 19	-	11 15 32	3 32	15 19	35 19 32 39	19 35 28 26	28 26 19	15 17 13 16	15 1 19	6 32 13	32 15	2 26 10	2 25 16
	19	19: Use of energy by moving	12 18 28 31	-	12 28	-	15 19 25	-	35 13 18	-	8 35 35	16 26 21 2	23 14 25	12 2 29	19 13 17 24	5 19 9 35	28 35 6 18	-	19 24 3 14	2 15 19	*	-	6 19 37 18	12 22 15 24	35 24 18 5	-	35 38 19 18	34 23 16 18	19 21 11 27	3 1 32	-	1 35 6 27	2 35 6	28 26 30	19 35	1 15 17 28	15 17 13 16	2 29 27 28	35 38	32 2	12 28 35
	20	20: Use of energy by stationary	-	19 9 6 27	-	-	-	-	-	-	-	36 37	-	-	27 4 29 18	35	-	-	-	19 2 35 32	-	*	-	-	28 27 18 31	-	-	3 35 31	10 36 23	-	-	10 2 22 37	19 22 18	1 4	-	-	-	-	19 35 16 25	-	1 6
	21	21: Power	8 36 38 31	19 26 17 27	1 10 35 37	-	19 38	17 32 13 38	35 6 38	30 6 25	15 35 2	26 2 36 35	22 10 35	29 14 2 40	35 32 15 31	26 10 28	19 35 10 38	16	2 14 17 25	16 6 19	16 6 19 37	-	*	10 35 38	28 27 18 38	10 19	35 20 10 6	4 34 19	19 24 26 31	32 15 2	32 2	19 22 31 2	2 35 18	26 10 34	26 35 10	35 2 10 34	19 17 34	20 19 30 34	19 35 16	28 2 17	28 35 34
	22	22: Loss of Energy	15 6 19 28	19 6 18 9	7 2 6 13	6 38 7	15 26 17 30	17 7 30 18	7 18 23	7	16 35 38	36 38	-	-	14 2 39 6	26	-	-	19 38 7	1 13 32 15	-	-	3 38	*	35 27 2 37	19 10	10 18 32 7	7 18 25	11 10 35	32	-	21 22 35 2	21 35 2 22	-	35 32 1	2 19	-	7 23	35 3 15 23	2	28 10 29 35
	23	23: Loss of substance	35 6 23 40	35 6 22 32	14 29 10 39	10 28 24	35 2 10 31	10 18 39 31	1 29 30 36	3 39 18 31	10 13 28 38	14 15 18 40	3 36 37 10	29 35 3 5	2 14 30 40	35 28 31 40	28 27 3 18	27 16 18 38	21 36 39 31	1 6 13	35 18 24 5	28 27 12 31	28 27 18 38	35 27 2 31	*	-	15 18 35 10	6 3 10 24	10 29 39 35	16 34 31 28	35 10 24 31	33 22 30 40	10 1 34 29	15 34 33	32 28 2 24	2 35 34 27	15 10 2	35 10 28 24	35 18 10 13	35 10 18	28 35 10 23
	24	24: Loss of Information	10 24 35	10 35 5	1 26	26	30 26	30 16	-	2 22	26 32	-	-	-	-	-	10	10	-	19	-	-	10 19	19 10	-	*	24 26 28 32	24 28 35	10 28 23	-	-	22 10 1	10 21 22	32	27 22	-	-	-	35 33	35	13 23 15
	25	25: Loss of Time	10 20 37 35	10 20 26 5	15 2 29	30 24 14 5	26 4 5 16	10 35 17 4	2 5 34 10	35 16 32 18	-	10 37 36 5	37 36 4	4 10 34 17	35 3 22 5	29 3 28 18	20 10 28 18	28 20 10 16	35 29 21 18	1 19 26 17	35 38 19 18	1	35 20 10 6	10 5 18 32	35 18 10 39	24 26 28 32	*	35 38 18 16	10 30 4	24 34 28 32	24 26 28 18	35 18 34	35 22 18 39	35 28 34 4	4 28 10 34	32 1 10	35 28	6 29	18 28 32 10	24 28 35 30	-
	26	26: Quantity of substance	35 6 18 31	27 26 18 35	29 14 35 18	-	15 14 29	2 18 40 4	15 20 29	-	35 29 34 28	35 14 3	10 36 14 3	35 14	15 2 17 40	14 35 34 10	3 35 10 40	3 35 31	3 17 39	-	34 29 16 18	3 35 31	35	7 18 25	6 3 10 24	24 28 35	35 38 18 16	*	18 3 28 40	13 2 28	33 30	35 33 29 31	3 35 40 39	29 1 35 27	35 29 25 10	2 32 10 25	15 3 29	3 13 27 10	3 27 29 18	8 35	13 29 3 27
	27	27: Reliability	3 8 10 40	3 10 8 28	15 9 14 4	15 29 28 11	17 10 14 16	32 35 40 4	3 10 14 24	2 35 24	21 35 11 28	8 28 10 3	10 24 35 19	35 1 16 11	-	11 28	2 35 3 25	34 27 6 40	3 35 10	11 32 13	21 11 27 19	36 23	21 11 26 31	10 11 35	10 35 29 39	10 28	10 30 4	21 28 40 3	*	32 3 11 23	11 32 1	27 35 2 40	35 2 40 26	-	27 17 40	1 11	13 35 8 24	13 35 1	27 40 28	11 13 27	1 35 29 38
	28	28: Measurement accuracy	32 35 26 28	28 35 25 26	28 26 5 16	32 28 3 16	26 28 32 3	26 28 32 3	32 13 6	-	28 13 32 24	32 2	6 28 32	6 28 32	32 35 13	28 6 32	28 6 32	10 26 24	6 19 28 24	6 1 32	3 6 32	-	3 6 32	26 32 27	10 16 31 28	-	24 34 28 32	2 6 32	5 11 1 23	*	-	28 24 22 26	3 33 39 10	6 35 25 18	1 13 17 34	1 32 13 11	13 35 2	27 35 10 34	26 24 32 28	28 2 10 34	10 34 28 32
	29	29: Manufacturing precision	28 32 13 18	28 35 27 9	10 28 29 37	2 32 10	28 33 29 32	2 29 18 36	32 23 2	25 10 35	10 28 32	28 19 34 36	3 35	32 30 40	30 18	3 27	3 27 40	-	19 26	3 32	32 2	-	32 2	13 32 2	35 31 10 24	-	32 26 28 18	32 30	11 32 1	-	*	26 28 10 36	4 17 34 26	-	1 32 35 23	25 10	-	26 2 18	-	26 28 18 23	10 18 32 39
	30	30: Object-affected harmful	22 21 27 39	2 22 13 24	17 1 39 4	1 18	22 1 33 28	27 2 39 35	22 23 37 35	34 39 19 27	21 22 35 28	13 35 39 18	22 2 37	22 1 3 35	35 24 30 18	18 35 37 1	22 15 33 28	17 1 40 33	22 33 35 2	1 19 32 13	1 24 6 27	10 2 22 37	19 22 31 2	21 22 35 2	33 22 19 40	22 10 2	35 18 34	35 33 29 31	27 24 2 40	28 33 23 26	26 28 10 18	*	-	24 35 2	2 25 28 39	35 10 2	35 11 22 31	22 19 29 40	22 19 29 40	33 3 34	22 35 13 24
	31	31: Object-generated harmful	19 22 15 39	35 22 1 39	17 15 16 22	-	17 2 18 39	22 1 40	17 2 40	30 18 35 4	35 28 3 23	35 28 1 40	2 33 27 18	35 1	35 40 27 39	15 35 22 2	15 22 33 31	21 39 16 22	22 35 2 24	19 24 39 32	2 35 6	19 22 18	2 35 18	21 35 2 22	10 1 34	10 21 29	1 22	3 24 39 1	24 2 40 39	3 33 26	4 17 34 26	-	*	-	-	-	-	19 1 31	2 21 27 1	2	22 35 18 39
	32	32: Ease of manufacture	28 29 15 16	1 27 36 13	1 29 13 17	15 17 27	13 1 26 12	16 40	13 29 1 40	35	35 13 8 1	35 12	35 19 1 37	1 28 13 27	11 13 1	1 3 10 32	27 1 4	35 16	27 26 18	28 24 27 1	28 26 27 1	1 4	27 1 12 24	19 35	15 34 33	32 24 18 16	35 28 34 4	35 23 1 24	-	1 35 12 18	-	24 2	-	*	2 5 13 16	35 1 11 9	2 13 15	27 26 1	6 28 11 1	8 28 1	35 1 10 28
	33	33: Ease of operation	25 2 13 15	6 13 1 25	1 17 13 12	-	1 17 13 16	18 16 15 39	1 16 35 15	4 18 39 31	18 13 34	28 13 35	2 32 12	15 34 29 28	32 35 30	32 40 3 28	29 3 8 25	1 16 25	26 27 13	13 17 1 24	1 13 24	-	35 34 2 10	2 19 13	28 32 2 24	4 10 27 22	4 28 10 34	12 35	17 27 8 40	25 13 2 34	1 32 35 23	2 25 28 39	-	2 5 12	*	12 26 1 32	15 34 1 16	32 26 12 17	-	1 34 12 3	15 1 28
	34	34: Ease of repair	2 27 35 11	2 27 35 11	1 28 10 25	3 18 31	15 13 32	16 25	25 2 35 11	1	34 9	1 11 10	13	1 13 2 4	2 35	11 1 2 9	11 29 28 27	1	4 10	15 1 13	15 1 28 16	-	15 10 32 2	15 1 32 19	2 35 34 27	-	32 1 10 25	2 28 10 25	11 10 1 16	10 2 13	25 10	35 10 2 16	-	1 35 11 10	1 12 26 15	*	7 1 4 16	35 1 13 11	-	34 35 7 13	1 32 10
	35	35: Adaptability or versatility	1 6 15 8	19 15 29 16	35 1 29 2	1 35 16	35 30 29 7	15 16	15 35 29	-	35 10 14	15 17 20	35 16	15 37 1 8	35 30 14	35 3 32 6	13 1 35	2 16	27 2 3 35	6 22 26 1	19 35 29 13	-	19 1 29	18 15 1	15 10 2 13	-	35 28	3 35 15	35 13 8 24	35 5 1 10	-	35 11 32 31	-	1 13 31	15 34 1 16	1 16 7 4	*	15 29 37 28	1	27 34 35	35 28 6 37
	36	36: Device complexity	26 30 34 36	2 26 35 39	1 19 26 24	26	14 1 13 16	6 36	34 26 6	1 16	34 10 28	26 16	19 1 35	29 13 28 15	2 22 17 19	2 13 28	10 4 28 15	-	2 17 13	24 17 13	27 2 29 28	-	20 19 30 34	10 35 13 2	35 10 28 29	-	6 29	13 3 27 10	13 35 1	2 26 10 34	26 24 32	22 19 29 40	19 1	27 26 1 13	27 9 26 24	1 13	29 15 28 37	*	15 10 37 28	15 1 24	12 17 28
	37	37: Difficulty of detecting	27 26 28 13	6 13 28 1	16 17 26 24	26	2 13 18 17	2 39 30 16	29 1 4 16	2 18 26 31	3 4 16 35	30 28 40 19	35 36 37 32	27 13 1 39	11 22 39 30	27 3 15 28	19 29 39 25	25 34 6 35	3 27 35 16	2 24 26	35 38	19 35 16	18 1 16 10	35 3 15 19	1 18 10 24	35 33 27 22	18 28 32 9	3 27 29 18	27 40 28 8	26 24 32 28	-	22 19 29 28	2 21	5 28 11 29	2 5	12 26	1 15	15 10 37 28	*	34 21	35 18
	38	38: Extent of automation	28 26 18 35	28 26 35 10	14 13 17 28	23	17 14 13	-	35 13 16	-	28 10	2 35	13 35	15 32 1 13	18 1	25 13	6 9	-	26 2 19	8 32 19	2 32 13	-	28 2 27	23 28	35 10 18 5	35 33	24 28 35 30	35 13	11 27 32	28 26 10 34	28 26 18 23	2 33	2	1 26 13	1 12 34 3	1 35 13	27 4 1 35	15 24 10	34 27 25	*	5 12 35 26
	39	39: Productivity	35 26 24 37	28 27 15 3	18 4 28 38	30 7 14 26	10 26 34 31	10 35 17 7	2 6 34 10	35 37 10 2	-	28 15 10 36	10 37 14	14 10 34 40	35 3 22 39	29 28 10 18	35 10 2 18	20 10 16 38	35 21 28 10	26 17 19 1	35 10 38 19	1	35 20 10	28 10 29 35	28 10 35 23	13 15 23	-	35 38	1 35 10 38	1 10 34 28	18 10 32 1	22 35 13 24	35 22 18 39	35 28 2 24	1 28 7 10	1 32 10 25	1 35 28 37	12 17 28 24	35 18 27 2	5 12 35 26	*

1. Segment:

Principle Explanation	Architectural Application
A. Divide an object into independent parts.	▪ In factory design, separate the office accommodation and manufacturing facility
B. Make an object easy to assemble or disassemble.	▪ Prefabricated construction.
C. Increase the degree of fragmentation or segmentation.	▪ Multi-pane windows.

Principle Usage	**Among the contradictions that this principle solves:**
	35/33 Adaptability and Versatility, and Ease of Operation. 29/39 Productivity and Manufacturing Precision 27/34 Reliability and Ease of repair.

2. Take Out (Removal/Extraction):

Principle Explanation	Architectural Application
A. Separate an interfering part (or property) from an object, or single out the only necessary part (or property) of an object.	▪ Locate noisy equipment (air-conditioning plant, etc) outside a building. ▪ Pedestrian/vehicle segregation.

Principle Usage	**Among the contradictions that this principle solves:**
	27/31 Reliability and Object affected harmful. 31/11 Object-generated harmful, and Stress or Pressure

3. Local Quality:

Principle Explanation	Architectural Application
A. Change an object's structure from uniform to non-uniform	▪Material surface treatments/coatings - self-cleaning paint, etc.
B. Change an external environment (or external influence) from uniform to non-uniform	▪Different security arrangements for front and back of shop.
C. Make each part of an object function in conditions most suitable for its operation	▪Different shaped rooms for different functions.
D. Make each part of an object fulfill a different and/or complementary useful function.	▪Fire-retarding paint
Principle Usage	**Among the contradictions that this principle solves:** ▪27/26 Reliability and Quantity of substance. ▪35/26 Adaptability and versatility, and Quantity of Substance.

4. Asymmetry:

Principle Explanation	Architectural Application
A. Change the shape or properties of an object from symmetrical to asymmetrical	▪Double doors where one leaf is wider than the other.
B. Change the shape of an object to suit external asymmetries (e.g. ergonomic features)	▪Human-shaped seating.
C. If an object is asymmetrical, increase its degree of asymmetry.	▪Compound/multi-sloped roofing.
Principle Usage	**Among the contradictions that this principle solves:** ▪33/8 Ease of Operation, and Volume. 35/34 Adaptability or Versatility, and Ease of Repair.

5. Merge

Principle Explanation	Architectural Application
A. Bring closer together (or merge) identical or similar objects or operations in space	▪Multi-purpose halls ▪Sandwich panels
B. Make objects or operations contiguous or parallel; bring them together in time	▪Prefabrication ▪"Design and Build" method of procurement (multi-skilling within company)

Principle Usage	Among the contradictions that this principle solves:
	▪28/27 Measurment accuracy and Reliability. ▪32/33 Ease of Manufacture and Ease of Operation.

6. Universality:

Principle Explanation	Architectural Application
A. Make a part or object perform multiple functions; eliminate the need for other parts.	▪Water tanks on top of buildings provide insulation and head for water supply
B. Use standardised features.	▪Use of Standards in e.g. safety regulations

Principle Usage	Among the contradictions that this principle solves:
	▪35/36 Adaptability or Versatility, and Productivity ▪36/6 Device Complexity, and Area of stationary

7. Nested Doll (1):

Principle Explanation	Architectural Application
A. Place one object inside another	▪False ceilings ▪Roller shutters
B. Place multiple objects inside others.	▪ Shopping centres
C. Make one part passes (dynamically) through a cavity in the other.	▪Sliding doors

Principle Usage	**Among the contradictions that this principle solves:**
	▪4/6 Length of stationary, and Area of stationary
	▪4/12 Length of stationary, and Shape.
	▪8/12 Volume, and Shape

Figure (3-9) Nesting Dolls
(http://upload.wikimedia.org/wikipedia/commons/thumb/d/d2/Russian-Matroshka_no_bg.jpg/750px-Russian-Matroshka_no_bg.jpg)

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(1) Russian Nesting Doll is a set of dolls of decreasing sizes placed one inside the other. It is also known as a matryoshka doll or babushka doll. The word "babushka" is the Russian word for grandmother. (en.wikipedia.org/wiki/Matryoshka_doll)

8. Counterweight (Anti-Weight)

Principle Explanation	**Architectural Application**
A. To compensate for the weight of an object, merge it with other objects that provide lift	▪Floating floor ▪Use of cranes
B. To compensate for the weight of an object, make it interact with the environment (e.g. use aerodynamic, hydrodynamic, buoyancy and other forces)	▪Design a building to float using a tanked basement ▪Passive solar heaters use natural convection currents to circulate water.
Principle Usage	**Among the contradictions that this principle solves:**
	▪35/27 Adaptability or Versatility, and Reliability. ▪33/27 Reliability and Ease of operation.

9. Prior Counteraction (Preliminary anti-action):

Principle Explanation	**Architectural Application**
A. If it will be necessary to perform an action with both harmful and useful effects, this action should be replaced with anti-actions to control harmful effects.	▪Use recycled materials ▪Use renewable energy
B. Create beforehand actions in an object that will oppose known undesirable working stresses later on.	▪Vapour-permeable paint helps prevent rot in wood
Principle Usage	**Among the contradictions that this principle solves:**
	▪6/4 Area of stationary, and Length of stationary. ▪36/33 Device complexity and Ease of operation.

10. Preliminary action:

Principle Explanation	Architectural Application
A. Perform, before it is needed, the required change of an object (either fully or partially).	▪Pre-fabricated buildings ▪Design for re-cyclability ▪Pre-pasted wall paper (1)
B. Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.	▪Pre-payment machines in car-parks
Principle Usage	**Among the contradictions that this principle solves:** ▪29/39 Manufacturing Precision and Productivity. ▪25/23 Loss of time and Loss of substance. ▪27/25 Reliability and Loss of time

11. Cushion:

Principle Explanation	Architectural Application
A. Prepare emergency means beforehand to compensate for the relatively low reliability of an object	▪Emergency stairways/fire-escapes.
Principle Usage	**Among the contradictions that this principle solves:** ▪27/25 Relaiability and Loss of time

12. Remove Tension (2) (Reduce mechanical movement)

Principle Explanation	Architectural Application
A. In a potential field, limit position changes (e.g. change operating conditions to eliminate the need to raise or lower objects in a gravity field).	▪Ramps for wheelchairs ▪Use cleaning platforms to clean large objects.
Principle Usage	**Among the contradictions that this principle solves:** ▪33/38 Ease of operation, and Extent of automation.

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(1) www.40triz.com
(2) In some sources:”Equipotentiality”.

13. Other Way Round (nigative to positive)

Principle Explanation	Architectural Application
A. Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it)	▪ Instead of providing more and more car parking, provide NO car parking
B. Make movable parts (or the external environment) fixed, and fixed parts movable.	▪ Instead of people's having to come to hospital use travelling medical facilities
C. Turn the object (or process) 'upside down'.	▪ Most architectural structures rely on compressive forces, use of tension wires/tensegrity (1) structures permits construction of lighter structures with greater internal space

Principle Usage	**Among the contradictions that this principle solves:**
	▪ 27/35 Reliability, and Adaptability and Versatility. ▪ 33/9 Ease of operation, and Speed. ▪ 2/6 Weight of stationary, and Area of stationary.

14. Curve

Principle Explanation	Architectural Application
A. Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones; move from flat surfaces to spherical ones; from parts shaped as a cube to ball-shaped structures.	▪ Use arches and domes for strength. ▪ Geodesic structures - maximum space coverage with minimum material usage.
B. Use rollers, balls, spirals, domes.	▪ Domed roofs ▪ Spiral plan for an infinitely extending museum
C. Go from linear to rotary motion (or vice versa)	▪ Revolving doors help keep heat inside a building.

Principle Usage	**Among the contradictions that this principle solves:**
	6/23 Area of stationary, and Loss of substace. 13/23 Stability of the object, Loss of substace.

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(1) Tensegrity is a portmanteau of tensional integrity. It refers to structures with an integrity based on a synergy between balanced tension and compression components.

15. Dynamize:

Principle Explanation	Architectural Application
A. Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.	▪ Self-regulating windows
B. Divide an object into parts capable of movement relative to each other.	▪ Movement joints. ▪ Bleacher seating (1).
C. If an object (or process) is rigid or inflexible, make it movable or adaptive.	▪ Multi-purpose halls
D. Increase the degree of free motion	▪ 'Moving internal wall' systems suit evolving needs of occupants.
Principle Usage	**Among the contradictions that this principle solves:** 6/35 Area of stationary, and Adaptability and Versatility. 35/33 Adaptability and Versatility, and Ease of operation.

16. Slightly Less/Slightly More (Partial, overdone or excessive action):

Principle Explanation	Architectural Application
A. If 100 percent of an object is hard to achieve using a given solution method then, by using 'slightly less' or 'slightly more' of the same method, the problem may be considerably easier to solve.	▪ Over spray when painting, then remove excess ▪ Design for say 95% of requirement is often the practical solution for e.g. heating systems, car parking.
Principle Usage	**Among the contradictions that this principle solves:** ▪ 6/35 Area of stationary, and Adaptability and Versatility. ▪ 33/6 Ease of operation, and Area of stationary.

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(1) Long rows of benches in sports fields, sometimes built in so that they slide on a track or on wheels and fold in an accordion-like manner.

Principle 17. Another dimension

Principle Explanation	Architectural Application
A. If an object contains or moves in a straight line, consider use of dimensions or movement outside the line.	▪ Pyramidal structures (non-vertical walled structures)
B. If an object contains or moves in a plane, consider use of dimensions or movement outside the current plane.	▪ Spiral staircase uses less floor area. ▪ Curved or profiled roofing materials have superior spanning capabilities.
C. Use a multi-storey arrangement of objects instead of a single-storey arrangement.	▪ Multi-storey office blocks or car-parks
D. Tilt or re-orient the object, lay it on its side.	▪ Angled glazing/tilting windows
E. Use 'another side' of a given area.	
Principle Usage	**Among the contradictions that this principle solves:**
	▪ 36/18 Device complexity and Illumination intensity ▪ 6/39 Area of stationary, and Productivity ▪ 4/6 Length of stationary, and Area of stationary ▪ 36/13 Device complexity and Stability

Principle 18. Mechanical vibration

Principle Explanation	Architectural Application
A. Cause an object to oscillate or vibrate.	▪ Use non-parallel walls to prevent acoustic standing waves
B. Increase its frequency (even up to the ultrasonic).	▪ Non-destructive crack detection using ultrasound
C. Use an object's resonant frequency.	▪ Use Helmholtz resonators to absorb sound
Principle Usage	**Among the contradictions that this principle solves:**
	▪ 11/2 Stress and weight of stationary object. ▪ 6/2 Area of stationary object and weight of stationary object.

19. Periodic Action

Principle Explanation	Architectural Application
A. Instead of continuous action, use periodic or pulsating actions.	▪ Take account of day/night temperature and light difference effects when designing thermal/illumination. ▪ Use railings or bollards instead of walls. shown in Fig.(3-10)
B. If an action is already periodic, change the periodic magnitude or frequency.	▪ Vary column spacing
C. Use pauses between actions to perform a different action.	▪ Refill WC cistern while not in use

Principle Usage	**Among the contradictions that this principle solves:**
	▪ 17/28 Temperature and Extent of automation ▪ 22/17 Loss of energy, and Temperature.

Figure (3-10) Bollards
(www.designbuild-network.com/contractors/site_security/atg-access/atg-access1.html)

20. Continuity of Useful Action

Principle Explanation	Architectural Application
A. Carry on work continuously; make all parts of an object work at full load or optimum efficiency, all the time.	▪ Multi-function spaces and personnel
B. Eliminate all idle or intermittent actions or work.	▪ Reduce or eliminate circulation by staff ▪ Reduce or eliminate circulation space

Principle Usage	**Among the contradictions that this principle solves:**
	▪ 9/22 Speed, and Loss of energy

21. Hurry (or skip through or Rushing through)

Principle Explanation	**Architectural Application**
A. Conduct a process, or certain stages (e.g. destructible, harmful or hazardous operations) at high speed.	▪ Cut plastic faster than heat can propagate in the material, to avoid deforming the shape.
Principle Usage	**Among the contradictions that this principle solves:**
	▪ 31/22 Object generated harmful, and Loss of energy.

22. Blessing in Disguise (1) (Convert harm into benefit)

Principle Explanation	**Architectural Application**
A. Use harmful factors (particularly, harmful effects of the environment or surroundings) to achieve a positive effect.	▪ Use waste heat to generate electric power.
B. Eliminate the primary harmful action by adding it to another harmful action to resolve the problem.	▪ Use toxic chemicals to protect timber from infestation and rot
C. Amplify a harmful factor to such a degree that it is no longer harmful.	▪ Fully glazed conservatories maximise solar gains, but cannot waste heat
Principle Usage	**Among the contradictions that this principle solves:**
	▪ 20/31 Use of energy by stationary, and Object generated harmful. ▪ 22/31 Loss of energy and Object generated harmful.

23. Feedback

Principle Explanation	**Architectural Application**
A. Introduce feedback (referring back, cross-checking) to improve a process or action.	▪ Motion sensitive lighting/toilet flush/etc systems
B. If feedback is already used, change its magnitude or influence in accordance with operating conditions.	▪ Involve manufacturers during early design stages.
Principle Usage	**Among the contradictions that this principle solves:**
	27/20 Reliability and Use of energy by stationary.

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(1) Idiom Definition for 'Blessing in disguise': If some bad luck or misfortune ultimately results in something positive, it's a blessing in disguise. (www.usingenglish.com)

24. Intermediary

Principle Explanation	Architectural Application
A. Use an intermediary carrier article or intermediary process.	▪ Small ceramic tiles stuck to a disposable sheet. ▪ Skirting boards protect delicate plaster from damage by vacuum cleaners, etc.
B. Merge one object temporarily with another (which can be easily removed).	

Principle Usage	**Among the contradictions that this principle solves:**
	33/39 Object affected harmful, and Productivity. 23/33 Loss of substance, and Ease of operation.

25. Self-Service

Principle Explanation	Architectural Application
A. Make an object serve or organise itself by performing auxiliary helpful functions	▪ Use building contours to channel wind energy towards wind-turbine
B. Use waste resources, energy, or substances.	▪ Use heat from a process to generate electricity. ▪ Grey water recycling systems

Principle Usage	**Among the contradictions that this principle solves:**
	33/2 Ease of operation, and Weight of stationary.

26. Copy

Principle Explanation	Architectural Application
A. Instead of an unavailable, expensive, fragile object, use simpler and inexpensive copies.	▪ Virtual reality
B. Replace an object, or process with optical copies.	▪ Do surveying from aerial photographs instead of on the ground
C. If visible optical copies are already used, move to infrared or ultraviolet copies.	▪ Detect heat losses through facades using infra-red photography

Principle Usage	**Among the contradictions that this principle solves:**
	36/28 Device complexity, and Measurment accuracy 28/6 Measurment accuracy, and Area of stationary. 28/22 Measurment accuracy and Loss of energy.

27. Cheap Disposable (or Cheap short-living objects)

Principle Explanation	**Architectural Application**
A. Replace an expensive object with a multiple of inexpensive objects, compromising certain qualities (such as service life, for instance).	▪ Regular painting to protect otherwise non-durable surfaces.

Principle Usage	**Among the contradictions that this principle solves:**
	33/27 Ease of Operation, and Reliability. 16/27 Durability of non moving object, and Reliability.

28. Mechanical Substitution
(Reverse) Replacement of a mechanical system:

Principle Explanation	**Architectural Application**
A. Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means.	▪ Motion-sensitive switches remove need for occupant having to locate mechanical switch
B. Use electric, magnetic and electromagnetic fields to interact with the object.	▪ Electric fence

Principle Usage	**Among the contradictions that this principle solves:**
	39/22 Productivity and Loss of energy. 21/39 Power and Productivity.

29. Pneumatics and hydraulics (Fluid)

Principle Explanation	**Architectural Application**
A. Use gas and liquid parts of an object instead of solid parts	▪ Warm air heating systems

Principle Usage	**Among the contradictions that this principle solves:**
	39/22 Productivity and Loss of energy. 21/12 Power and Shape

30. Flexible shells and thin films

Principle Explanation	Architectural Application
A. Use flexible shells and thin films instead of three-dimensional structures.	▪ I, C or U beams instead of solid section beams. ▪ "Stretch" ceilings.
B. Isolate the object from the external environment using flexible shells and thin films.	▪ Bubble-wrap ▪ Egg-box

Principle Usage	**Among the contradictions that this principle solves:**
	2/6 Weight of stationary, and Area. 13/23 Stability and Loss of substance

Principle 31. Porous materials

Principle Explanation	Architectural Application
A. Make an object porous or add porous elements (inserts, coatings, etc.).	▪ Cavity wall insulation ▪ Drill holes in a structure to reduce the weight.
B. If an object is already porous, use the pores to introduce a useful substance or function.	▪ At night pass air through hollow structure to cool it.

Principle Usage	**Among the contradictions that this principle solves:**
	27/21 Reliability and Power.

Principle 32. Colour changes

Principle Explanation	Architectural Application
A. Change the colour of an object or its external environment	▪ Electro glass (1) shown in Fig. (2-9) or photo-chromic (2) glass.
B. Change the transparency of an object or its external environment	▪ Put glass in doors on corridors so that users can see if someone is on the other side.
C. In order to improve observability of things that are difficult to see, use coloured additives or luminescent elements	▪ Fluorescent safety markings help guide people out of a building after power failure ▪ Use opposing colours to increase visibility - e.g. butchers use green decoration to make the red in meat look redder
D. Change the emissivity (3) properties of an object subject to radiant heating	▪ Use of light and dark coloured panels to assist thermal management in building spaces.
Principle Usage	**Among the contradictions that this principle solves:** 6/21 Area of stationary, and Power. 6/27 Area of stationary, and Reliability. 37/25 Defficulty of detecting, and Loss of time.

Figure (3-11):
Electro-Glass Turning from Transparent to Translucent State.
(www.digitalsignage-usa.com/electric-glass)

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(1) Electro glass is a glass that goes from a transparent state to a white translucent state, at the flip of a switch. (www.digitalsignage-usa.com/electric-glass)

(2) Photo-chromic is a glass that darkens when exposed to light but regains its original transparency a few minutes after light is removed; the rate of clearing increases with temperature. (www.answers.com/topic/photochromic-glass)

(3)The emissivity of a material (usually written ε or e) is the ratio of energy radiated by a particular material to energy radiated by a black body at the same temperature.

Principle 33. Homogeneity

Principle Explanation		Architectural Application
A. Make objects interacting with a given object of the same material (or material with identical properties).		▪ To avoid cracking make sure that abutting materials have similar coefficients of expansion
Principle Usage	**Among the contradictions that this principle solves:**	
	16/30 Durability of non moving object, and Object affected harmful	

Principle 34. Discarding and recovering

Principle Explanation		Architectural Application
A. Make portions of an object that have fulfilled their functions go away (discard by dissolving, evaporating, etc.) or modify these directly during operation.		▪ Ice structures: use water ice or carbon dioxide (dry ice) to make a template for a rammed earth structure, such as a temporary dam. Fill with earth, then, let the ice melt to leave the final structure.
B. Conversely, restore consumable parts of an object directly in operation		▪ Grey-water recycling systems
Principle Usage	Among the contradictions that this principle solves:	
	39/12 Productivity and Shape. 33/25 Ease of operation, and Loss of time.	

Principle 35. Parameter Changes

Principle Explanation	Architectural Application
A. Change an object's physical state (e.g. to a gas, liquid, or solid).	▪ Adhesives instead of mechanical joining methods. ▪ Use injected (liquid) silicon rubber sealants ▪ Transport oxygen or nitrogen or petroleum gas as a liquid, instead of a gas, to reduce volume.
B. Change the concentration or consistency.	▪ Dilute paint to achieve ‘wash’ effects ▪ Different grades of MDF
C. Change the degree of flexibility.	▪ Use adjustable dampers to provide active vibration damping in buildings
D. Change the pressure.	▪ Use vacuum suction to improve flow of concrete/sealants/etc into awkward shaped cavities.
Principle Usage	**Among the contradictions that this principle solves:** 27/12 Reliability and Shape. 27/8 Reliability, and Volume of stationary.

Principle 36. Phase transitions

Principle Explanation	Architectural Application
Use phenomena occurring during phase transitions (e.g. volume changes, loss or absorption of heat, etc.).	▪ Use melting ice as a way of gently lowering heavy structures
Principle Usage	**Among the contradictions that this principle solves:** 11/6 stress or pressure and area of stationary object

Principle 37. Thermal expansion

Principle Explanation	Architectural Application
A. Use thermal expansion (or contraction) of materials.	▪ Fit a tight joint together by cooling the inner part to contract, heating the outer part to expand, putting the joint together, and returning to equilibrium. ▪ Expansion joints
B. If thermal expansion is being used; use multiple materials with different coefficients of thermal expansion	▪ Bi-metallic hinges offer self-opening windows/ventilators in order to regulate climate inside building, e.g. industrial greenhouse. (1)

Principle Usage	**Among the contradictions that this principle solves:**
	39/35 Productivity, and Adaptability and Versatility. 14/30 Stength and Object affected harmful. 20/30 Use of energy by stationary, and Object-affected harmful.

Principle 38. Enriched atmosphere

Principle Explanation	Architectural Application
A. Replace common air with oxygen-enriched air.	▪ Place plants in living spaces
B. Replace enriched air with pure oxygen.	▪ Cut at a higher temperature using an oxy-acetylene torch (2)
C. Expose air or oxygen to ionizing radiation (3)	
D. Use ionized oxygen.	▪ Ionize air to trap pollutants in an air cleaner (4).
E. Replace ozonized (or ionized) oxygen with ozone.	

Principle Usage	**Among the contradictions that this principle solves:**
	27/39 Reliability and Productivity. 21/6 Power, and Area.

---

(1) Previously mentioned at p.66.
(2) Using fuel gases and oxygen to weld and cut metals
(3) Electromagnetic waves which are energetic enough to detach electrons from atoms or molecules
(4) This example does not belong to Mann and Catháin; it is a general example from (www.triz40.com). In fact, there is no Architecture examples identified for C, D or E.

Principle 39. Inert atmosphere

Principle Explanation	Architectural Application
A. Replace a normal environment with an inert one.	▪ Creation of ‘calm’ spaces into office buildings
B. Add neutral parts, or inert additives to an object.	▪ Non-flammable additives into cavity wall foams. ▪ Sound absorbing panels. ▪ Hollow block floors
Principle Usage	**Among the contradictions that this principle solves:**
	31/27 Object generated harmful, and Reliability.

Principle 40. Composite materials

Principle Explanation	Architectural Application
A. Change from uniform to composite (multiple) materials where each material is tuned to a particular functional requirement.	▪ Rebar reinforced concrete. ▪ Mixed fibre carpets.
Principle Usage	**Among the contradictions that this principle solves:**
	27/16 Reliability, and Durability of non moving object.

3.2.1.4. Case Study of TRIZ analysis with Biomimicry on the cuticle of Arthropods:

The following case study illustrates how TRIZ could be used to solve a contradiction in a biological model.

The function of the outer covering of cuticle of arthropods is providing a stiff support for the insect, attachment for muscles, mechanical protection and control of shape (1).

In the natural design of the cuticle of arthropods, three different conflicts will be viewed, to find out how they were solved, and how that TRIZ can offer the solutions.

1- **A uniformly stiff skeleton does not permit movement, so hinged areas are needed. This has been achieved by making the cuticle softer along the hinge line.**

This appears to be the same as TRIZ inventive principle 3: *Local quality,* which is characterized by the following statements:

- Use gradients instead of uniformity (change an object’s structure, or its environment, from homo- to heterogeneous);
- Compartmentalize (make each part of an object more adapted to its own purpose);
- Introduce multifunctionality, make each part of an object fulfils a different function like a pencil with an eraser or a hammer with a nail-puller.

<u>To translate the principle into cuticular structure:</u>

The hinge areas have different amounts and orientation of chitin, which is the fibrous component, and the matrix proteins are chemically different from the stiff areas and so more hydrated and softer.

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(1) Vincent, J., et al., “Biomimetics: Its Practice and Theory".

2. Stiffness requires extensive cross-linking of the matrix protein, which is against the use of the cuticle as a resorbable chemical energy store (important for insects which feed only intermittently).

The resolution of this conflict is achieved by TRIZ inventive principle 2: *Extraction*. It tells: “Extract, isolate or remove an interfering or necessary part or property from an object.”

<u>To translate the principle into cuticular structure:</u>

The arthropode has a minimum of two layers of cuticle, the inner one being only partially stabilized and available for resorption.

Since this layer is more likely to take loads in tension, its ability to resist Compression is less important.

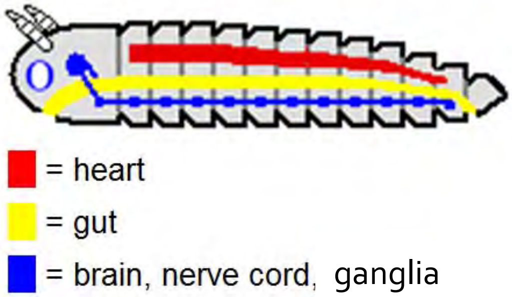

Figure (3-12) Basic Arthropods Body Structure
www.en.wikipedia.org/wiki/Arthropod#cite_note-23

3- An external skeleton is a barrier to transmission of information about the external environment, a function provided by sensory hairs and holes

Resolution here is achieved by IP (1) 31 *Porous materials*, which states: make an object porous; use the pores to introduce a useful substance or function.

Applying TRIZ to biological model like arthropods instead of human patents leads us to a new method, the BioTRIZ. It will be shown in the next section.

---

(1) IP means Inventive Principle.

3.2.2. BioTRIZ Matrix:

3.2.2.1. From TRIZ to BioTRIZ

- **PRIZM: ‘TRIZ Modernized’:**

A group of biologists made a condensed version of the TRIZ contradiction matrix, by rearranging the 39 features and 40 inventive principles into 6 meta-categories, or operational fields (1).

These 6 new features are:

Substance, Structure, Energy, Information, Space and Time.

This new 6x6 version of the TRIZ contradiction matrix was called PRIZM. PRIZM a Russian language acronym for "Pravila Reshenija Izobretatel’skih Zadach Modernizirovannye" translated as ‘The Rules of Inventive Problem Solving, Modernized’ (2).

Vincent states that this condensed matrix, which is shown in table (3-4), is easier to use than the 39 contradictions system (2).

- **BioTRIZ:**

A biological version of PRIZM was then constructed, that more closely reflects the biological route to the resolution of conflicts. This new version of PRISM was called Bio TRIZ. It is shown in table (3-5).

The basis on which the 39 features and 40 principles are distributed under these six fields are shown in table (3-6)

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(1) Craig, S., et al., "Tow New Environmental Building Technologies, One New Design Method: Infrared Transparent Insulation, Biodegradable Concrete Formwork and BioTRIZ".

(2) Vincent, J., et al., "Biomimetics: Its Practice and Theory”.

Table (3-4) PRIZM Matrix Derived from Standard TRIZ Matrix. *(Vincent, et al., 2006)*

fields	substance	structure	space	time	energy	information
substance	6 10 26 27 31 40	27	14 15 29 40	3 27 38	10 12 18 19 31	3 15 22 27 29
structure	15	18 26	1 13	27 28	19 36	1 23 24
space	8 14 15 29 39 40	1 30	4 5 7–9 14 17	4 14	6 8 15 36 37	1 15–17 30
time	3 38	4 28	5 14 30 34	10 20 38	19 35 36 38	22 24 28 34
energy	8 9 18 19 31 36–38	32	12 15 19 30 36–38	6 19 35–37	14 19 21 25 36–38	2 19 22
information	3 11 22 25 28 35	30	1 4 16 17 39	9 22 25 28 34	2 6 19 22 32	2 11 12 21–23 27 33 34

Table (3-5) PRIZM Matrix Derived from Biological Effects. *(Vincent, et al., 2006)*

fields	substance	structure	space	time	energy	information
substance	13 15 17 20 31 40	1–3 15 24 26	1 5 13 15 31	15 19 27 29 30	3 6 9 25 31 35	3 25 26
structure	1 10 15 19	1 15 19 24 34	10	1 2 4	1 2 4	1 3 4 15 19 24 25 35
space	3 14 15 25	2–5 10 15 19	4 5 36 14 17	1 19 29	1 3 4 15 19	3 15 21 24
time	1 3 15 20 25 38	1–4 6 15 17 19	1–4 7 38	2 3 11 20 26	3 9 15 20 22 25	1–3 10 19 23
energy	1 3 13 14 17 25 31	1 3 5 6 25 35 36 40	1 3 4 15 25	3 10 23 25 35	3 5 9 22 25 32 37	1 3 4 15 16 25
information	1 6 22	1 3 6 18 22 24 32 34 40	3 20 22 25 33	2 3 9 17 22	1 3 6 22 32	3 10 16 23 25

Table (3-6): Distribution of Altshuller's Conflict Features to the PRIZM Categories.

(Formed according to Vincent et al., 2006) (1):

Operational Field and its Meaning	Contradicting Parameters or Features	Operational Field and its Meaning	Contradicting Parameters or Features
1- Substance Add, remove or change properties of a material.	▪ Weight of moving and stationary object (1,2)[2] ▪ Loss of substance (23) ▪ Quantity of substance (26)	**4- Time** Change speed of process or order of actions	▪ Speed (9) ▪ Duration of action of moving and stationary object (15, 16) ▪ Loss of time (25) ▪ Productivity (39)
2- Structure Add, remove or Regroup structural parts	▪ Stability of the object's composition (13) ▪ Manufacturing precision(29) ▪ Ease of manufacture (32) ▪ Device complexity (36)	**5- Energy** Change energy source or field	▪ Total force (10) ▪ Stress or pressure (11) ▪ Strength (14) ▪ Temperature (17) ▪ Illumination intensity (18) ▪ Use of energy by moving and stationary object (19, 20) ▪ Power (21) ▪ Loss of energy (22)
3- Space Change position or shape of system or parts	▪ Length of moving and stationary object (3, 4) ▪ Area of moving and stationary object (5, 6) ▪ Volume of moving and stationary object (7, 8) ▪ Shape (12)	**6- Information** Change interactions or regulation of a system or its elements	▪ Loss of information (24) ▪ Reliability (27) ▪ Measurement accuracy (28) ▪ Object-affected and object-generated harmful factors (30, 31) ▪ Ease of operation and repair (33, 34) ▪ Adaptability or versatility (35) ▪ Difficulty of detecting and measuring (37, 38)

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(1)Vincent, J., et al., "Biomimetics: Its Practice and Theory", Appendix 2, P. 11

(2)The numbers between parentheses express the number of the feature in TRIZ matrix.

3.2.2.2. Comparison between Biology and Technology:

- **<u>General Observations</u>**

Vincent and his colleagues then compared the two 6x6 matrices, and found out the following:

1. Although the problems commonly are very similar, the inventive principles that nature and technologies use to solve problems can be very different.
2. The similarity between the TRIZ and BioTRIZ matrices is only 12%.
3. Human technology solves problems largely by manipulating the use of Energy, whereas biology uses Information and Structure, two factors largely ignored by technology.
   This can be seen in Fig. (3-13) and (3-14).

In technology, the most important variable for the solution of a problem is manipulation of **energy** usage, as it reaches 60% as shown in fig.(3-13). The use of **material** is the second important variable. Thus, when we face an engineering problem, we tend to achieve a solution by changing (usually increasing) the energy requirement or changing the amount or type of the material.

While in biology the most important variables for the solution of problems are **information** and **structure** as shown in Fig. (3-14).

In addition, Fig (3-13) and (3-14) give us a clear idea of the progressive development of each variable through the scale development (1).

---

(1) A nanometer (nm) is a unit of length in the metric system, equals to one billionth of a metre or one millionth of a millimetre. It can be written as 10^{-9} m
A micrometre or micron (μm) is one millionth of a metre, or one thousandth of a millimetre. It can be written as 10^{-6} m.
Few figures that illustrate the nano scale are placed in the appendices, at pp. 241-244.

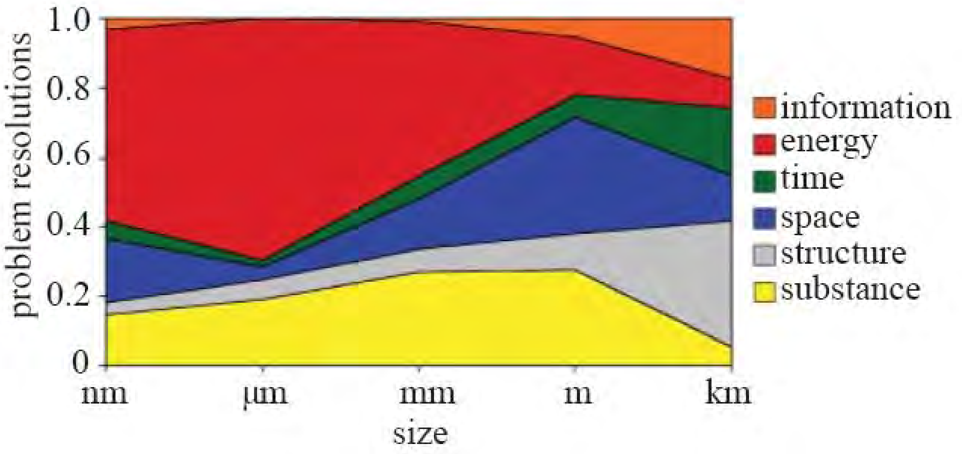

Figure (3-13) Engineering TRIZ Solutions Arranged According to Size/ Hierarchy.
(Vincent, et al., 2006)

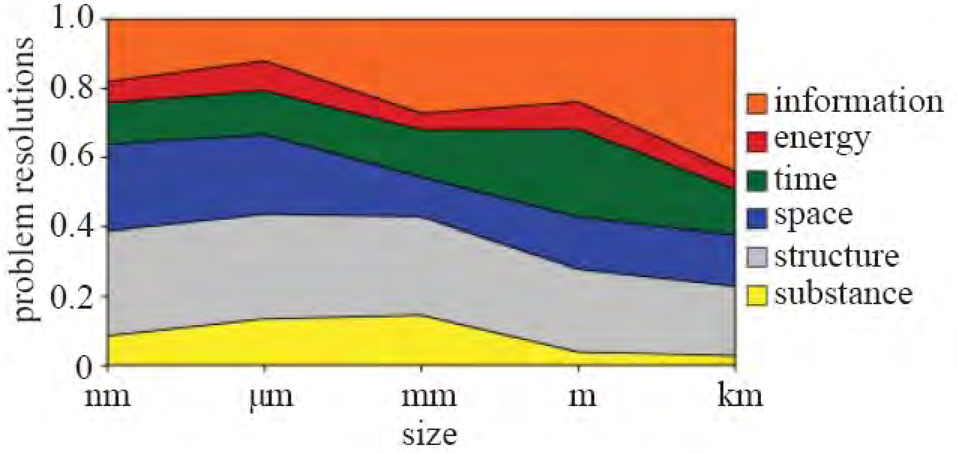

Figure (3-14) Biological Effects Arranged According to Size/ Hierarchy.
(Vincent, et al., 2006)

Another fact can be detected, that the proportional distribution of features in biology, shown in Fig. (3-14) is more regular than in technology, shown in Fig. (3-13), where we can observe acute changes in the proportional distribution of some features.

This means that in nature, in all scale levels, all the features participate in the solution with relatively equal roles. *No acute changes*, the way the features *jump* in Fig. (3-13), and *No feature disappears*, the way the “information” feature disappeared in the micrometer scale level.

- **Scale Level Analysis:**

Two scale levels will be focused on, in order to figure out the relative importance of the solving features to each other, in those scale levels.

The largest and the smallest scale levels were chosen, the scale from 1 meter to 1 kilometer and the scale from 1 nanometer to 1 micron.

Buildings lie in the scale that ranges from 1 meter to one kilometer, so this is the scale that will be analyzed first.

❖ Engineering and Biological Solution that lies in the scale from 1 meter to 1 kilometer:

a- Engineering Solution:

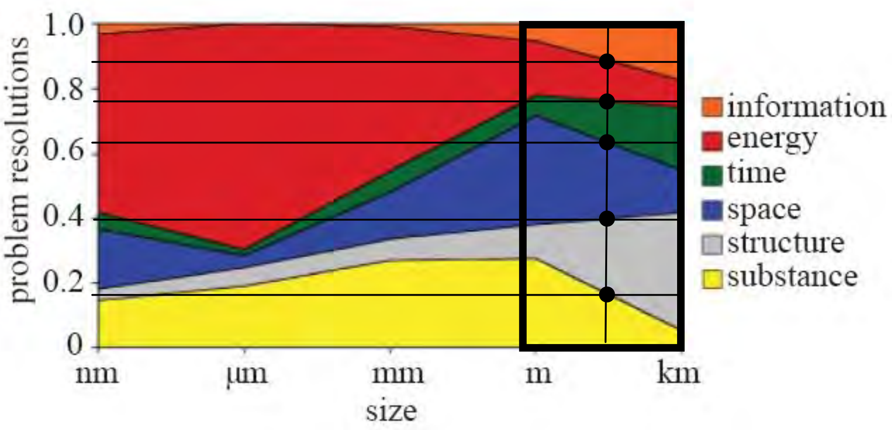

Figure (3-15) Engineering TRIZ Solutions Arranged According to Size/ Hierarchy
(Vincent, et al., 2006)
with a Focus on the Range From One Meter to One Kilometer.
(By researcher)

Fig (3-15) shows that in the range from one meter to one kilometer, in the engineerig solution, the proportion occupied by each variable is as follows:

1- Space : 24%
2- Structure : 24%
3- Substance : 16%
4- Information :12%
5- Energy : 12%
6- Time : 12%

b- Biological Solution:

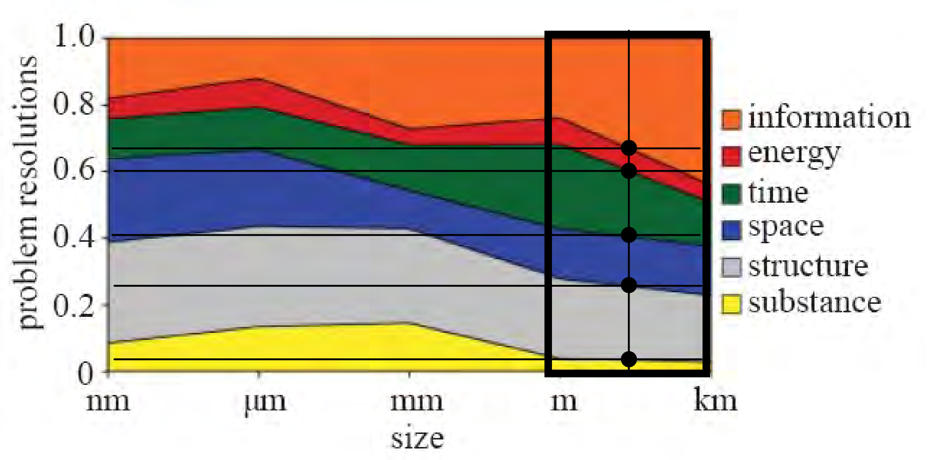

Figure (3-16) Biological Effects Arranged According to Size/ Hierarchy
(Vincent, et al., 2006)
with a Focus on the Range from One Meter to One Kilometer.
(By researcher)

In biological solution, the proportion occupied by each variable is as follows:

1- Information : 32%
2- Time : 20%
3- Structure : 20%
4- Space : 16%
5- Energy : 8%
6- Substance : 4%

- **Engineering and Biological Solution that lies in the scale from 1 nanometer to 1 micron:**

a- Engineering Solution:

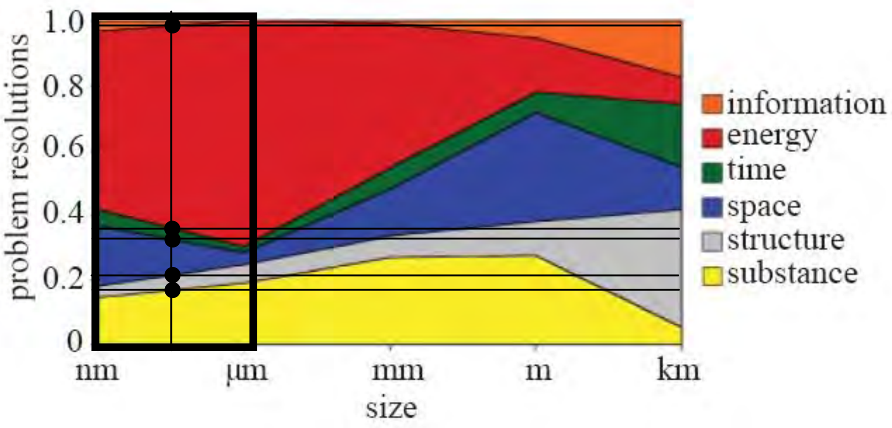

Figure (3-17) Engineering TRIZ Solutions Arranged According to Size/ Hierarchy.
(Vincent, et al., 2006)
with a Focus on the Range from One Nanometer to One Micrometer.
(By researcher)

Fig (3-17) shows that in the size from nanometer to micron, In Engineering solution, the proportion occupied by each variable is as follows:

1- Energy : 60%
2- Substance : 18%
3- Space : 12%
4- Time : 4%
5- Structure : 4%
6- Information : 2%

b- Biological Solution:

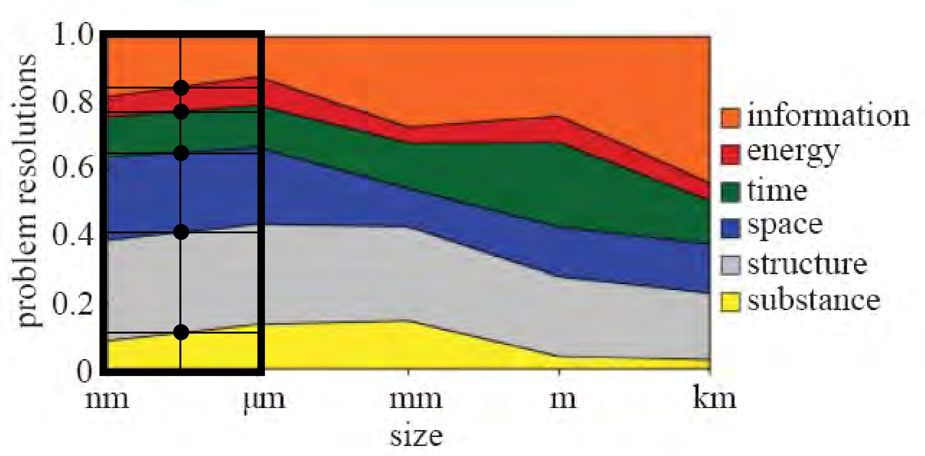

Figure (3-18) Biological Effects Arranged According to Size/ Hierarchy.
(Vincent, et al., 2006)
with a Focus on the Range from One Nanometer to One Micrometer.
(By researcher)

Fig (3-18) shows that in Biological solutions, the proportion occupied by each variable is as follows:

1- Structure : 30%
2- Space : 22%
3- Information : 16%
4- Time : 14%
5- Substance : 10%
6- Energy : 8%

Table (3-7): Percentage Participation of the Six Features in the Solutions of Engineering and Biological Problems. *(By researcher):*

No.	Feature	Percentage Participation			
		Engineering Problems		Biological problems	
		nm-um	m-km	Nm-um	m-km
1	Information	2%	12%	16%	32%
2	Energy	60%	12%	8%	8%
3	Time	4%	12%	14%	20%
4	Space	12%	24%	22%	16%
5	Structure	4%	24%	30%	20%
6	Substance	18%	16%	10%	4%

What concerns us most, as architects, in the context of our interest in biomimicry is the last column that shows the percentage participation of each feature in the solutions of the biological contradictions in the scale that ranges from 1m to 1km, the scale in which most of the architectural activities take place.

Putting the features in the right order leads to table (3-8).

Table (3-8): The Six Features Ordered According to Their Percentage Participation in the Solutions of the Biological Contradictions in the Scale of 1m-1km. *(By researcher):*

No.	Feature	Biology
		m-km
1	Information	32%
2	Structure	20%
3	Time	20%
4	Space	16%
5	Energy	8%
6	Substance	4%

In this context, the distribution of Altshuler’s 40 inventive principles to the six categories of BioTRIZ that was set by Vincent et al. (2006), must be viewed.

Table (3-9) Distribution of Altshuller's Inventive Principles to the PRIZM Categories.
(Formed according to Vincent et al., 2006)(1):

Operational Field and its Meaning	Inventive Principles	Operational Field and its Meaning	Inventive Principles
1- Substance Add, remove or change properties of a material.	▪ Copying (26)(2) ▪ Color change (32) ▪ Homogeneity (33) ▪ Parameter change (35) ▪ Phase transition (36)	**4- Time** Change speed of process or order of actions	▪ Preliminary Action (10) ▪ Beforehand Cushioning (11) ▪ Dynamics (15) ▪ Periodic Action (19) ▪ Continuity of useful action (20) ▪ Rushing through (21) ▪ Cheap short-lived objects (27)
2- Structure Add, remove or Regroup structural parts	▪ Segmentation (1) ▪ Taking out (2) ▪ Local quality (3) ▪ Merging (5) ▪ Universality (6) ▪ Nested Doll (7) ▪ Abundance (16) ▪ Intermediary (24) ▪ Discarding and recovering (34) ▪ Composite materials (40)	**5- Energy** Change energy source or field	▪ Anti-Weight (8) ▪ Preliminary Anti-Action (9) ▪ Equipotentiality (12) ▪ Mechanical vibration (18) ▪ Mechanics substitution (28) ▪ Pneumatics and Hydraulics (29) ▪ Thermal Expansion (37) ▪ Strong oxidants (38) ▪ Inert Atmosphere (39)
3- Space Change position or shape of system or parts	▪ Asymmetry (4) ▪ Spheroidality, curvature (14) ▪ Flexible shells and thin films (30) ▪ Porous Materials (31) ▪ Another dimension (17)	**6- Information** Change interactions or regulation of a system or its elements	▪ The other way around (13) ▪ Blessing in disguise (22) ▪ Feedback (23) ▪ Self-service (25)

---

(1)Vincent, J., et al., "Biomimetics: Its Practice and Theory", Appendix 2, P. 11
(2)The numbers between parentheses express the number of the inventive principle.

To follow the natural models, the following should be considered: Architecture should depend most on Information, and use less and less energy and materials. The least amount of substance and energy with the most amount of information could present a more efficient architecture model.

3.2.2.3. Biomimetic design Methodology using BioTRIZ:

- **Original Methodology by Vincent et al.:**

The sequence of solving a problem using TRIZ according to Vincent, et al., (2006) is (1):

- **Define the problem** in the most general, yet precise way.
  It's essential here to avoid specific directions of thought and premature solutions. Also special terminology should be avoided as it confines the thinking space to the existing sphere.
- Analyze and understand the problem and so **uncover the main conflicts** or contradictions.
- Compare the solutions recommended by biology and TRIZ.
  Find the common solutions for biological and engineering fields. List the technical and biological principles thus recommended.
- Build a bridge from natural to technical design, based on these common solutions

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(1)Vincent, J., et al., "Biomimetics: Its Ppractice and Theory", p.479.

- **Reframed Methodology:**

  This is how the previous steps could be reframed:

  - Step 1: Define the problem in the most general yet precise way (Ask the question).
  - Step 2: Form the conflicts or contradictions

    The more conflicts you form, the more rich your “vocabulary of solutions” will be. To form a conflict, you may need first, to ask a more precise question.
  - Step 3: Look up your conflicts in TRIZ matrix. Table (3-3) (1)
    - List the inventive principles resulted
    - Interpret these principles into applicable solutions.
  - Step 4: : look up the conflict in the BioTRIZ matrix, in table (3-5) (2)
    - You will have first, to turn the contradicting parameters into BioTRIZ features using table (3-6) (3)
    - List the inventive principles resulted
    - Interpret these principles into applicable solutions.
  - Step 5: Repeat steps (3 and 4) for each of your conflicts
  - Step 6: List the common solutions resulted from both TRIZ and BioTRIZ matrices.
  - Step 7: Design your solution according to the interpretation of these common principles.
    - The other principles may also help to figure the solution.

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(1) Table (3-3) at P. 104.
(2) Table (3-5) at P. 127.
(3) Table (3-6) at P. 128.

According to a case study (1) that was held by Vincent, et al., (2006), table (3-10) could be formed.

Table (3-10): Biomimetic Contradiction Solving Form,
(Formed by researcher out of Vincent et al., 2006):

<table>
<tr><td colspan="6">The Problem Definition
(The Basic Question)</td></tr>
<tr><td colspan="2">Conflict 1
(Question Form 1)
F[2] (No.) vs. F(No.)</td><td colspan="2">Conflict 2
(Question Form 2)
F (No.) vs. F (No.)</td><td colspan="2">Conflict 3
(Question Form 3)
F (No.) vs. F (No.)</td></tr>
<tr><td>TRIZ</td><td>BioTRIZ</td><td>TRIZ</td><td>BioTRIZ</td><td>TRIZ</td><td>BioTRIZ</td></tr>
<tr><td>IP[3](No.)
IP (No.)
IP (No.)
IP (No.)</td><td>IP (No.)
IP (No.)
IP (No.)
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IP (No.)</td><td>IP (No.)
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IP (No.)</td><td>IP (No.)
IP (No.)
IP (No.)</td></tr>
<tr><td colspan="6">The Common Inventive Principles
IP (No.)
IP (No.)
IP (No.)</td></tr>
<tr><td colspan="6">The Solution</td></tr>
</table>

---

(1) They designed a new kind of tires called cat's claw wheel. Although the task was a physical problem not architectural one, but it could give us a model to use when we design biomimetically. The case study is viewed in the appendices, p. 237.

(2) F means contradicting Feature or parameter.

(3) IP means Inventive Principle.

3.2.2.4. Architectural Case Study using BioTRIZ:

A research was accomplished to demonstrate how Bio TRIZ has been applied to resolve a tradeoff in the radiative cooling task (1).

The methodology that Craig has followed could be viewed in Fig. (3-19).

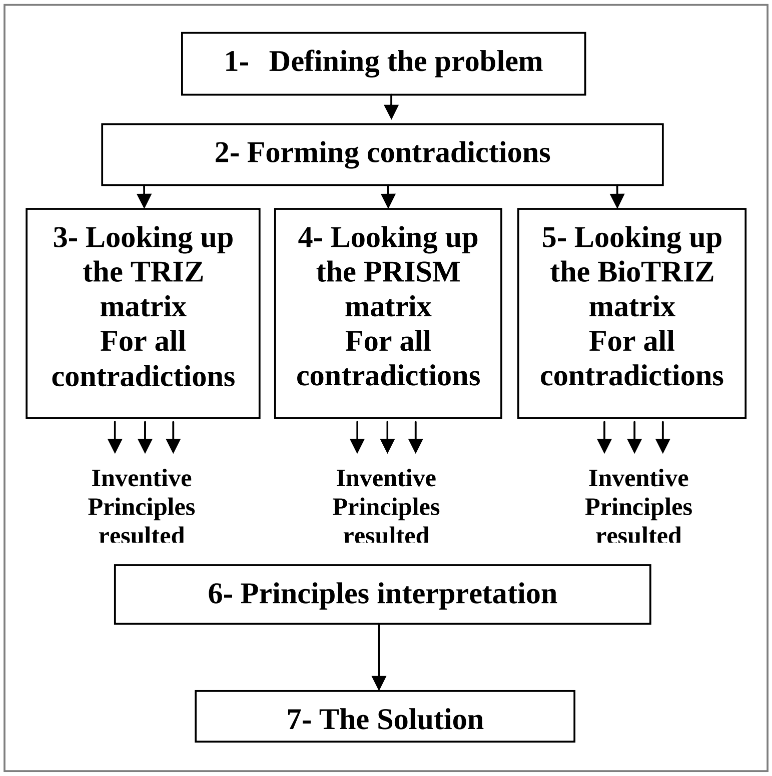


Figure (3-19) Methodology Followed by Craig, et al. in a Radiative Cooling Task Using BioTRIZ
(Formed by Researcher)

The Problem Background:

The sky temperature is often much lower than ambient air temperature at ground level, particularly in clear and dry conditions.

Craig, states the following;

The sky emits longwave infrared radiation downwards; a building emits longwave infrared radiation upwards: if the latter outweighs the former, net radiative cooling occurs.

---

(1) Craig, S., et al., "BioTRIZ Suggests Radiative Cooling of Buildings Can Be Done Passively by Changing the Structure of Roof Insulation to Let Longwave Infrared Pass".

1-Defining the problem:

"The insulation in a standard roof stops the sun and convection from warming the thermal mass. But it also restricts the mass's longwave view of the cool sky.

As we see in Fig (3-20) the useful interaction in longwave radiation from the building to the sky is insufficient, due to the roof insulation, while harmful interactions like long wave radiation from the sky, shortwave radiation from the sun, convection and conduction through the ambient temperature take place.

2-Forming contradictions:

- Craig and his colleagues first determined the parameters or features that best describe the problem, as the following:

  - Feature No. (17), Temperature: The thermal condition of the object or system.
  - Feature No. (18), Illumination Intensity: Light flux per unit area, brightness, light quality, etc.

  - Feature No. (20), Use of Energy by a Stationary Object: Energy required to do a job.
  - Feature No. (22), Loss of energy: Energy that does not contribute to the job being done.

The four features or parameters fall into the operational field “Energy".

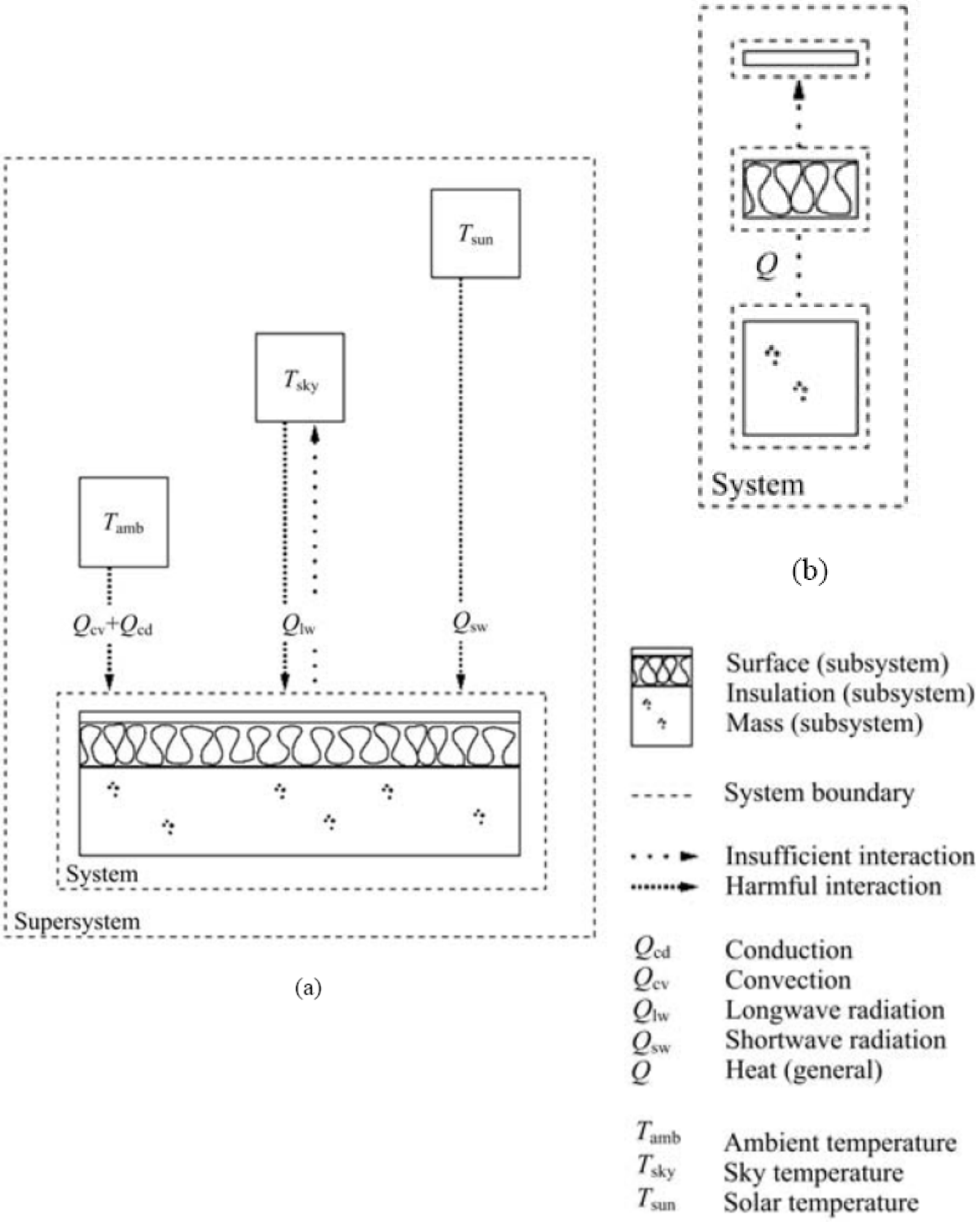


Figure (3-20) A Roof and Its Thermal Interactions with the Sun, Sky and External Ambient Temperature.
(Craig, 2008a)

Craig and his colleagues then began to describe the problem as conflicts in 12 different ways; only the four following conflicts were mentioned in their research:

- The mass should be allowed to reach thermal equilibrium with the sky (17) without counterproductive energy inputs from the super system (22).

  The undesired heat gained from the sky was considered as loss of energy (1).

  The improving feature: F 17 Temperature.

  The worsening feature: F 22 Loss of energy.

- Increase the longwave exchange between mass and sky (18) without counterproductive energy inputs from the super system (22).

  The improving feature: F 18 Illumination intensity

  The worsening feature: F 22 loss of energy.

- Increase the longwave exchange between mass and sky (18) without incoming shortwave radiation and local convection increasing the temperature of the mass (17).

  The desired longwave exchange is expressed by feature 18 Illumination intensity.

  The improving feature: F 18 Illumination intensity.

  The worsening feature: F 17 Temperature, raised by undesired shortwave radiation and local convection.

- Increase the longwave exchange between mass and sky (18) without reducing the amount of heat rejected by the mass (20)

  The improving feature: F 18 Illumination intensity

  The worsening feature: F 20 Use of energy by stationary object.

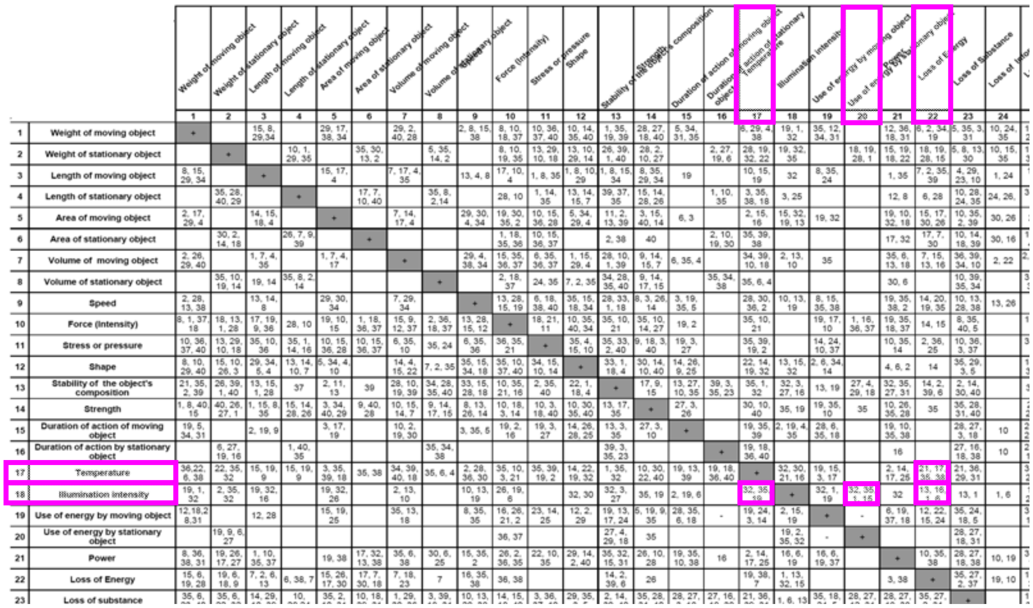
---

(1) The architectural application in chapter four followed the same consideration, at p. 158.

3- Looking up the TRIZ Matrix:

Table (3-11) shows an example of looking up TRIZ matrix for the four conflicts. The table is a part of TRIZ matrix.

Table (3-11) Looking up TRIZ Matrix in a Radiative Cooling Task Accomplished by Craig et al., *(By researcher)*:



		Weight of moving object	Weight of stationary object	Length of moving object	Length of stationary object	Area of moving object	Area of stationary object	Volume of moving object	Volume of stationary object	Speed	Force (Intensity)	Stress or pressure	Shape	Stability of the object's composition	Strength	Duration of action of moving object	Duration of action by stationary object	Temperature	Illumination intensity	Use of energy by moving object	Use of energy by stationary object	Power	Loss of Energy	Loss of Substance	Loss of Info
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Weight of moving object	+		15, 8, 29,34		29, 17, 38, 34		29, 2, 40, 28		2, 8, 15, 38	8, 10, 18, 37	10, 36, 37, 40	10, 14, 35, 40	1, 35, 19, 39	28, 27, 18, 40	5, 34, 31, 35		6, 29, 4, 38	19, 1, 32	35, 12, 34, 31		12, 36, 18, 31	6, 2, 34, 19	5, 35, 3, 31	10, 24, 35
2	Weight of stationary object		+		10, 1, 29, 35		35, 30, 13, 2		5, 35, 14, 2		8, 10, 19, 35	13, 29, 10, 18	13, 10, 29, 14	26, 39, 1, 40	28, 2, 10, 27		2, 27, 19, 6	28, 19, 32, 22	19, 32, 35		18, 19, 28, 1	15, 19, 18, 22	18, 19, 28, 15	5, 8, 13, 30	10, 15, 35
3	Length of moving object	8, 15, 29, 34		+		15, 17, 4		7, 17, 4, 35		13, 4, 8	17, 10, 4	1, 8, 35	1, 8, 10, 29	1, 8, 15, 34	8, 35, 29, 34	19		10, 15, 19	32	8, 35, 24		1, 35	7, 2, 35, 39	4, 29, 23, 10	1, 24
4	Length of stationary object		35, 28, 40, 29		+		17, 7, 10, 40		35, 8, 2,14		28, 10	1, 14, 35	13, 14, 15, 7	39, 37, 35	15, 14, 28, 26		1, 10, 35	3, 35, 38, 18	3, 25			12, 8	6, 28	10, 28, 24, 35	24, 26,
5	Area of moving object	2, 17, 29, 4		14, 15, 18, 4		+		7, 14, 17, 4		29, 30, 4, 34	19, 30, 35, 2	10, 15, 36, 28	5, 34, 29, 4	11, 2, 13, 39	3, 15, 40, 14	6, 3		2, 15, 16	15, 32, 19, 13	19, 32		19, 10, 32, 18	15, 17, 30, 26	10, 35, 2, 39	30, 26
6	Area of stationary object		30, 2, 14, 18		26, 7, 9, 39		+				1, 18, 35, 36	10, 15, 36, 37		2, 38	40		2, 10, 19, 30	35, 39, 38				17, 32	17, 7, 30	10, 14, 18, 39	30, 16
7	Volume of moving object	2, 26, 29, 40		1, 7, 4, 35		1, 7, 4, 17		+		29, 4, 38, 34	15, 35, 36, 37	6, 35, 36, 37	1, 15, 29, 4	28, 10, 1, 39	9, 14, 15, 7	6, 35, 4		34, 39, 10, 18	2, 13, 10	35		35, 6, 13, 18	7, 15, 13, 16	36, 39, 34, 10	2, 22
8	Volume of stationary object		35, 10, 19, 14	19, 14	35, 8, 2, 14				+		2, 18, 37	24, 35	7, 2, 35	34, 28, 35, 40	9, 14, 17, 15		35, 34, 38	35, 6, 4				30, 6		10, 39, 35, 34	
9	Speed	2, 28, 13, 38		13, 14, 8		29, 30, 34		7, 29, 34		+	13, 28, 15, 19	6, 18, 38, 40	35, 15, 18, 34	28, 33, 1, 18	8, 3, 26, 14	3, 19, 35, 5		28, 30, 36, 2	10, 13, 19	8, 15, 35, 38		19, 35, 38, 2	14, 20, 19, 35	10, 13, 28, 38	13, 26
10	Force (Intensity)	8, 1, 37, 18	18, 13, 1, 28	17, 19, 9, 36	28, 10	19, 10, 15	1, 18, 36, 37	15, 9, 12, 37	2, 36, 18, 37	13, 28, 15, 12	+	18, 21, 11	10, 35, 40, 34	35, 10, 21	35, 10, 14, 27	19, 2		35, 10, 21		19, 17, 10	1, 16, 36, 37	19, 35, 18, 37	14, 15	8, 35, 40, 5	
11	Stress or pressure	10, 36, 37, 40	13, 29, 10, 18	35, 10, 36	35, 1, 14, 16	10, 15, 36, 28	10, 15, 36, 37	6, 35, 10	35, 24	6, 35, 36	36, 35, 21	+	35, 4, 15, 10	35, 33, 2, 40	9, 18, 3, 40	19, 3, 27		35, 39, 19, 2		14, 24, 10, 37		10, 35, 14	2, 36, 25	10, 36, 3, 37	
12	Shape	8, 10, 29, 40	15, 10, 26, 3	29, 34, 5, 4	13, 14, 10, 7	5, 34, 4, 10		14, 4, 15, 22	7, 2, 35	35, 15, 34, 18	35, 10, 37, 40	34, 15, 10, 14	+	33, 1, 18, 4	30, 14, 10, 40	14, 26, 9, 25		22, 14, 19, 32	13, 15, 32	2, 6, 34, 14		4, 6, 2	14	35, 29, 3, 5	
13	Stability of the object's composition	21, 35, 2, 39	26, 39, 1, 40	13, 15, 1, 28	37	2, 11, 13	39	28, 10, 19, 39	34, 28, 35, 40	33, 15, 28, 18	10, 35, 21, 16	2, 35, 40	22, 1, 18, 4	+	17, 9, 15	13, 27, 10, 35	39, 3, 35, 23	35, 1, 32	32, 3, 27, 16	13, 19	27, 4, 29, 18	32, 35, 27, 31	14, 2, 39, 6	2, 14, 30, 40	
14	Strength	1, 8, 40, 15	40, 26, 27, 1	1, 15, 8, 35	15, 14, 28, 26	3, 34, 40, 29	9, 40, 28	10, 15, 14, 7	9, 14, 17, 15	8, 13, 26, 14	10, 18, 3, 14	10, 3, 18, 40	10, 30, 35, 40	13, 17, 35	+	27, 3, 26		30, 10, 40	35, 19	19, 35, 10	35	10, 26, 35, 28	35	35, 28, 31, 40	
15	Duration of action of moving object	19, 5, 34, 31		2, 19, 9		3, 17, 19		10, 2, 19, 30		3, 35, 5	19, 2, 16	19, 3, 27	14, 26, 28, 25	13, 3, 35	27, 3, 10	+		19, 35, 39	2, 19, 4, 35	28, 6, 35, 18		19, 10, 35, 38		28, 27, 3, 18	10
16	Duration of action by stationary object		6, 27, 19, 16		1, 40, 35				35, 34, 38					39, 3, 35, 23			+	19, 18, 36, 40				16		27, 16, 18, 38	10
17	Temperature	36,22, 6, 38	22, 35, 32	15, 19, 9	15, 19, 9	3, 35, 39, 18	35, 38	34, 39, 40, 18	35, 6, 4	2, 28, 36, 30	35, 10, 3, 21	35, 39, 19, 2	14, 22, 19, 32	1, 35, 32	10, 30, 22, 40	19, 13, 39	19, 18, 36, 40	+	32, 30, 21, 16	19, 15, 3, 17		2, 14, 17, 25	21, 17, 35, 38	21, 36, 29, 31	
18	Illumination intensity	19, 1, 32	2, 35, 32	19, 32, 16		19, 32, 26		2, 13, 10		10, 13, 19	26, 19, 6		32, 30	32, 3, 27	35, 19	2, 19, 6		32, 35, 19	+	32, 1, 19	32, 35, 1, 15	32	13, 16, 1, 6	13, 1	1, 6
19	Use of energy by moving object	12,18,28,31		12, 28		15, 19, 25		35, 13, 18		8, 35, 35	16, 26, 21, 2	23, 14, 25	12, 2, 29	19, 13, 17, 24	5, 19, 9, 35	28, 35, 6, 18	-	19, 24, 3, 14	2, 15, 19	+	-	6, 19, 37, 18	12, 22, 15, 24	35, 24, 18, 5	
20	Use of energy by stationary object		19, 9, 6, 27								36, 37			27, 4, 29, 18	35				19, 2, 35, 32	-	+			28, 27, 18, 31	
21	Power	8, 36, 38, 31	19, 26, 17, 27	1, 10, 35, 37		19, 38	17, 32, 13, 38	35, 6, 38	30, 6, 25	15, 35, 2	26, 2, 36, 35	22, 10, 35	29, 14, 2, 40	35, 32, 15, 31	26, 10, 28	19, 35, 10, 38	16	2, 14, 17, 25	16, 6, 19	16, 6, 19, 37		+	10, 35, 38	28, 27, 18, 38	10, 19
22	Loss of Energy	15, 6, 19, 28	19, 6, 18, 9	7, 2, 6, 13	6, 38, 7	15, 26, 17, 30	17, 7, 30, 18	7, 18, 23	7	16, 35, 38	36, 38			14, 2, 39, 6	26			19, 38, 7	1, 13, 32, 15			3, 38	+	35, 27, 2, 37	19, 10
23	Loss of substance	35, 6,	35, 6,	14, 29,	10,	35, 2,	10, 18,	1, 29,	3, 39,	10, 13,	14, 15,	3, 36,	29, 35,	2, 14,	35, 28,	28, 27,	27, 16,	21, 36,	1, 6, 13	35, 18,	28, 27,	28, 27,	35, 27,	+	

Out of TRIZ matrix we can list the inventive principles that are recommended to solve the four conflicts in table (3-12).

Table (3-12) Inventive Principles Recommended by TRIZ to Solve Four Contradictions of Total 12 Contradictions Formed by Craig et al., in a Radiative Cooling Task *(By researcher)*:

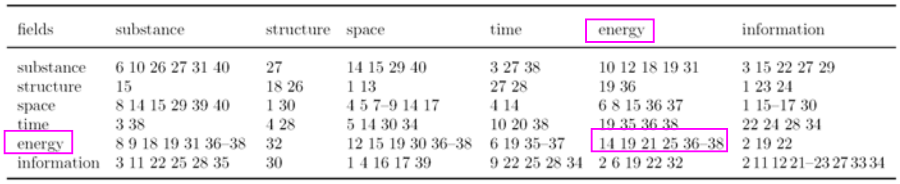
	Contradicting Features	Inventive Principles used to solve the conflicts			
Conflict No. 1	17 vs. 22	21 Hurry	17 Another Dimension	35 Parameter Change	38 Enriched atmosphere
Conflict No. 2	18 vs. 17	32 color change	35 Parameter change	19 Periodic Action	
Conflict No. 3	18 vs. 20	32 color change	35 Parameter change	1 Segmentation	15 Dynamize
Conflict No. 4	18 vs. 22	13 Other Way Round	16 Slightly Less/Slightly More	1 Segmentation	6 Universality

4- Looking up the PRISM Matrix :

Since all parameters fall into the operational field “Energy", we will look up the PRISM only once.

Table (3-13) shows the conflict looked up in the PRISM matrix, and table (3-14) demonstrates the inventive principles thus recommended.

Table (3-13) Looking up PRISM in a Radiative Cooling Task Accomplished by Craig et al., *(By researcher)*:



fields	substance	structure	space	time	energy	information
substance	6 10 26 27 31 40	27	14 15 29 40	3 27 38	10 12 18 19 31	3 15 22 27 29
structure	15	18 26	1 13	27 28	19 36	1 23 24
space	8 14 15 29 39 40	1 30	4 5 7–9 14 17	4 14	6 8 15 36 37	1 15–17 30
time	3 38	4 28	5 14 30 34	10 20 38	19 35 36 38	22 24 28 34
energy	8 9 18 19 31 36–38	32	12 15 19 30 36–38	6 19 35–37	14 19 21 25 36–38	2 19 22
information	3 11 22 25 28 35	30	1 4 16 17 39	9 22 25 28 34	2 6 19 22 32	2 11 12 21–23 27 33 34

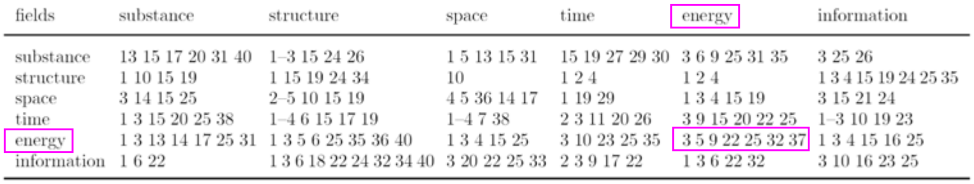
Table (3-14) Inventive Principles Recommended by PRISM to Solve the Four Contradictions Formed by Craig et al., in a Radiative Cooling Task *(By researcher)*:

Operational field	Inventive Principles recommended by PRISM to solve the conflict					
Energy vs. energy	14 Curvature	19 Periodic Action	21 Hurry	25 Self-Service	36 Phase Transition	38 Enriched atmosphere

5- Looking up the BioTRIZ matrix:

Table (3-15) shows the conflict looked up in the BioTRIZ matrix, while table (3-15) demonstrates the inventive principles thus recommended.

Table(3-15) Looking up BioTRIZ in a Radiative Cooling Task Accomplished by Craig et al., *(By researcher)*:



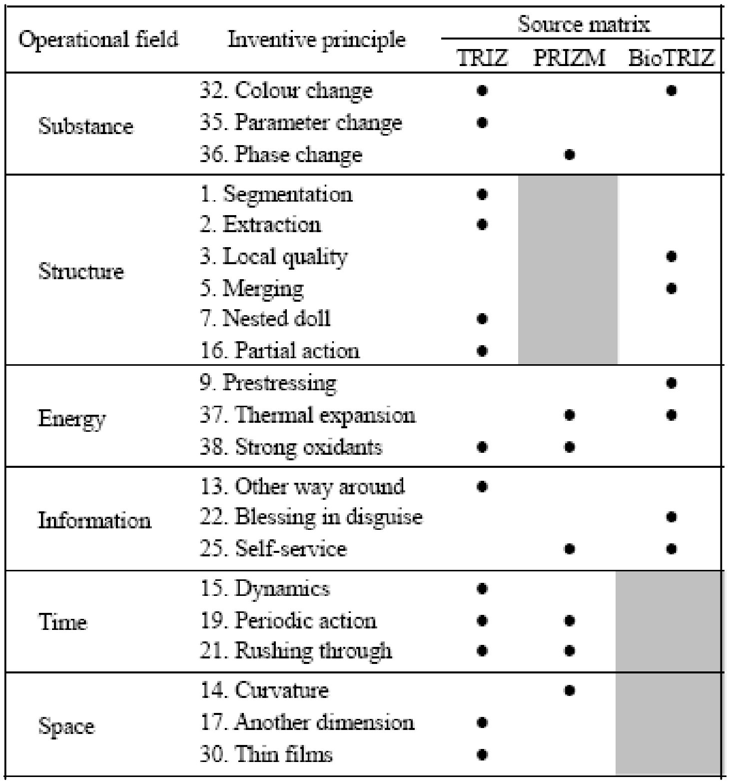
fields	substance	structure	space	time	energy	information
substance	13 15 17 20 31 40	1–3 15 24 26	1 5 13 15 31	15 19 27 29 30	3 6 9 25 31 35	3 25 26
structure	1 10 15 19	1 15 19 24 34	10	1 2 4	1 2 4	1 3 4 15 19 24 25 35
space	3 14 15 25	2–5 10 15 19	4 5 36 14 17	1 19 29	1 3 4 15 19	3 15 21 24
time	1 3 15 20 25 38	1–4 6 15 17 19	1–4 7 38	2 3 11 20 26	3 9 15 20 22 25	1–3 10 19 23
energy	1 3 13 14 17 25 31	1 3 5 6 25 35 36 40	1 3 4 15 25	3 10 23 25 35	3 5 9 22 25 32 37	1 3 4 15 16 25
information	1 6 22	1 3 6 18 22 24 32 34 40	3 20 22 25 33	2 3 9 17 22	1 3 6 22 32	3 10 16 23 25

Table (3-16) Inventive Principles Recommended by BioTRIZ to Solve the Four Contradictions Formed in a Radiative Cooling Task Accomplished by Craig et al., *(By researcher)*:

Operational field	Inventive Principles recommended by BioTRIZ to solve the conflict						
Energy vs. energy	3 Local quality	5 Merge	9 Preliminary anti-action	22 Blessing in Disguise	25 Self-Service	32 Color Change	37 Thermal Expansion

As mentioned before, Craig and his Colleagues have formed 12 conflicts, not only the four conflicts that they had mentioned. Looking up these 12 conflicts in TRIZ, PRISM and BioTRIZ matrices led up to a set of principles listed in table (3-17).

Table (3-17) The Inventive Principles Offered by All Three Matrices *(Craig, 2008a)*:



Operational field	Inventive principle	Source matrix		
		TRIZ	PRIZM	BioTRIZ
Substance	32. Colour change	●		●
	35. Parameter change	●		
	36. Phase change		●	
Structure	1. Segmentation	●		
	2. Extraction	●		
	3. Local quality			●
	5. Merging			●
	7. Nested doll	●		
	16. Partial action	●		
Energy	9. Prestressing			●
	37. Thermal expansion		●	●
	38. Strong oxidants	●	●	
Information	13. Other way around	●		
	22. Blessing in disguise			●
	25. Self-service		●	●
Time	15. Dynamics	●		
	19. Periodic action	●	●	
	21. Rushing through	●	●	
Space	14. Curvature		●	
	17. Another dimension	●		
	30. Thin films	●		

6- Principles Interpretation:

- IP 32 Color change: suggests adjusting the spectral properties of a substance.
- IP 35 Parameter change: suggests adjusting one of the physical parameters.

Both IP 32 and IP 35 could be interpreted as increasing the longwave transparency of the insulation, it is ***the use of an insulation material that retards convective and conductive heat transfer, but not radiative transfer***.

- IP 2 Extraction: suggests extracting the harmful part of the insulation.
- IP 3 Local quality: suggests changing the insulation from uniform to non uniform

Application of IP 2 and IP 3 could be ***an empty vertical pathways in the insulation*** that would give the mass an infrared view of the sky.

A honeycomb structure, for instance, might form an infrared transparent insulator, as it would allow air to stagnate during radiation cooling.

- IP 30 Flexible shells and thin films: suggests replacing the insulation with some sort of membrane that isolates the mass from the harmful heat sources in the environment, like a ***form of spectrally selective glazing*** or infrared transparent films used as convection guards.
- IP 17 Transition to another dimension: suggests layering the longwave transparent membranes in multiple layers to arrest convection further

  It also suggests an ***external shading system*** that follows the sun or even a ***well placed tree*** that might give a roof system enough open shading for daytime radiative cooling.
- IP 15 Dynamize: suggests ***mobilizing the mass*** or the insulation to give way to the longwave radiation.
- IP 19 Periodic action: suggests ***pulsating heat rejection*** in tune with, for instance, the day and night cycles.

  In combination with IP 21 Rushing through, IP 19 Periodic action suggests chopping up the flow into alternating pulses.
- IP 25 Self service: suggests that the system regulates itself.

- IP 22 Blessing in disguise: suggests turning harmful factors from the environment into a benefit.
- IP 37 Thermal Expansion: suggests using thermal expansion or contraction of a material or ***several materials with different expansion coefficients***, to create some useful movement.

The combination of the three principles suggests some sort of ***deployable structure that connects and disconnects the mass to the sky, according to the temperature.***

> **The way Craig and his colleagues used to extract solutions from the principles shows that we need a great deal of thinking flexibility to turn principles into solutions**

7-The Solution:

According to Craig, the simplest solution is the structural change in the insulation, as showing fig. (3-21)

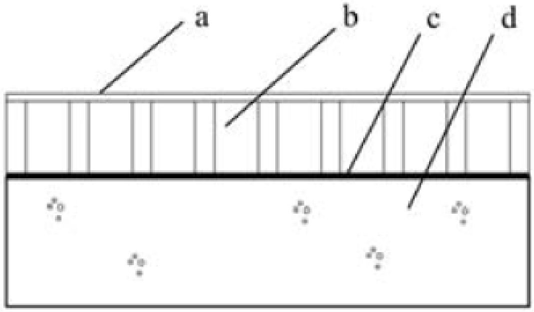


Figure (3-21) A Cool Roof for Hot Countries (Not to Scale), Suggested by Craig, et al..
(a) Shortwave reflector/longwave transmitter/convection guard e.g. thin white film.
(b) Honeycomb: insulates from ambient heat gain, but allows longwave radiation to pass.
(c) Radiator: e.g. concrete surface painted black.
(d) Thermal mass: e.g. concrete.
(Craig, 2008a)

In the cool roof, suggested by Craig, the concrete mass will reject thermal radiation to the sky, and be protected from solar radiation and the warm surrounding air.

Summary:

Chapter three tries to figure out and analyze all the methodologies of biomimetic design in order to present one or more methods that architects can use.

Two deferent approaches were viewed, those concerned with solving problems and contradictions. Fig. (3-22) illustrates the methods.

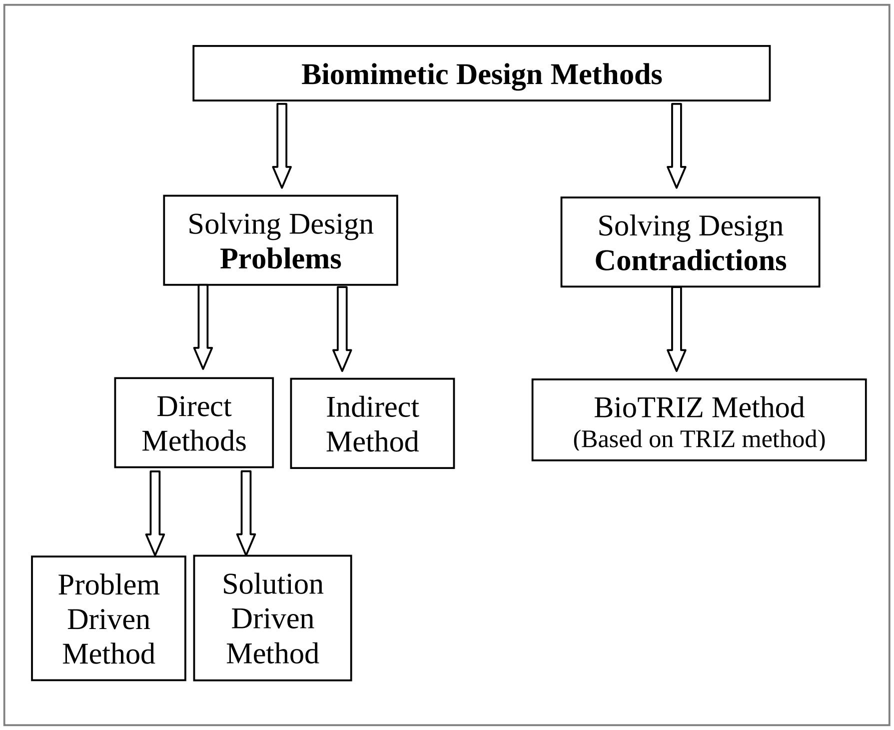


Figure (3-22) Biomimetic Design Methods

Conclusions:

1. BioTRIZ method has already helped a group of specialists to innovate a cool roof for hot countries. In a typical environmental architecture task, though it may concern those who are specialists in building technology rather than architects.

2. When using TRIZ and BioTRIZ methods, a great deal of thinking flexibility is needed to turn principles into solutions.

3. To design Biomimetic solution ***to uncover conflicts***, you can:
    a) follow the steps:
    - Step 1: Define the problem in the most general yet precise way
        - (Ask the question).
    - Step 2: Form the conflicts or contradictions
        - The more conflicts you form, the more rich your "vocabulary of solutions" will be.
        - To form a conflict, you may need first, to ask a more precise question.
    - Step 3: Look up your conflicts in TRIZ matrix. Table (3-3)(1)
        - List the inventive principles resulted
        - Interpret these principles into applicable solutions.
    - Step 4: : look up the conflict in BioTRIZ matrix, in table (3-5)(2)
        - You will have first, to turn the contradicting parameters into BioTRIZ features using table (3-6)(3)
        - List the inventive principles resulted
        - Interpret these principles into applicable solutions.
    - Step 5: Repeat steps (3 and 4) for each of your conflicts.
    - Step 6: List the common solutions resulted from both TRIZ and

---

(1) Table (3-3) at p. 104.
(2) Table (3-5) at p. 127.
(3) Table (3-6) at p. 128.

BioTRIZ matrices.

- Step 7: Design your solution according to the interpretation of these common principles.

  The other principles may also help to figure the solution.

b) Use table (3-10). It can help in comparing between inventive principles.

Table (3-10): Biomimetic Contradiction Solving Form

(Formed by researcher out of Vincent et al., 2006):

The Problem Definition (The Basic Question)					
Conflict 1 (Question Form 1) F(1)(No.) vs. F (No.)		Conflict 2 (Question Form 2) F (No.) vs. F (No.)		Conflict 3 (Question Form 3) F (No.) vs. F (No.)	
TRIZ	**BioTRIZ**	**TRIZ**	**BioTRIZ**	**TRIZ**	**BioTRIZ**
IP(2)(No.) IP (No.) IP (No.) IP (No.)	IP (No.) IP (No.) IP (No.) IP (No.) IP (No.)	IP (No.) IP (No.) IP (No.) IP (No.)	IP (No.) IP (No.) IP (No.)	IP (No.) IP (No.) IP (No.) IP (No.) IP (No.) IP (No.)	IP (No.) IP (No.) IP (No.)
The Common Inventive Principles IP (No.) IP (No.) IP (No.)					
The Solution					

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(1) F: means contradicting Feature or parameter.
(2) IP: means Inventive Principle.

4. To design Biomimetic solution ***to solve a design problem,*** you can:

   a) Use a direct way by following the steps:

   1-Form a question:

   Ask: "What do I want my design to do?”

   2-Biologize the question:

   Ask: "How does nature do this in its environment?”

   3-Find the model:

   Search for and choose the best organism that solves your problem.

   The champion adapter is the organism whom survival depend on answering this question.

   4-Anlyze the model:

   Study the mechanism and/or form that enable the organism to accomplish the function, consider the morphology, the scale and any other influencing factors.

   5-Term the strategy:

   Put the principles you've learned in the previous step in abstract words.

   6-Design solution:

   Design your own solution based on the abstract principle you have formed.

   7-Review solution:

   Check if your solution is:

   - Completely able to answer your question or there are related new sub-problems need to be solved.
   - Consistent with life principles or not.

   8-Form new questions:

   According to your answers in the previous step, form new question: "What do I want my design to do?

b) **Use an Indirect way**, by taking the natural designs principles in mind, trying to achieve as many of them as possible in the design. Those Principles are:

   1. Natural designs depend *totally on natural sources*, and *diversity of possibilities*. Among all sources, *Sunlight* has a special importance.
   2. Natural designs depends upon *total recycling*, where *waste* of a species *is food* for another, *symbiotic relationships* helps achieving the zero waste concept, and this leads to the principle: *don't foul your nest,* where wastes could really foul the nest.
   3. Natural designs respect the environmental *limits*, whilst ignoring these limits may also foul the nest. According to this respect, natural designs also *adjust to the here and now,* in another word, *it requires local expertise.*
   4. Natural designs depend on *fractals* where beauty hides and the design may extend without planning ahead. Natural designs also depend upon building *networks* instead of linearity, which depends on certain nodes.
   5. Natural designs use only the *necessary resources,* and *avoid overbuilding*
   6. Natural designs use the *functional form*, and rely upon *swarm intelligence*.

5. In case the designer is impressed with one of the wonders of God's creatures, he can go through a creative design experience by following the “Solution Driven Method”.

   The steps are:

   - Step 1: Biological Solution Identification:

     The design process begins with a particular biological solution in mind.
   - Step 2: Define the Biological Solution:

     Identify the structure or mechanism found in the biological solution that is responsible on achieving the function required. (Check step 4 in method 1 of "Design looking to biology").
   - Step 3: Principle Extraction:

     Extract important principles into a "solution-neutral form" removing as many constraints as possible. (Check step 5 in method 1 of "Design looking to biology").
   - Step 4: Reframe the Solution:

     "Humanize” the Problem-Solution pair

     The solution and applicable principles must be reframed in a context useful to human engineers. Since principles are typically already abstract; this may involve abstracting the solution’s problem (but not always).
   - Step 5: Problem Search:

     Find an existing or define a new problem to which the solution applies.
   - Step 6: Problem Definition:
   - Step 7: Principle Application:

     Apply the relevant solution principles to the new problem.

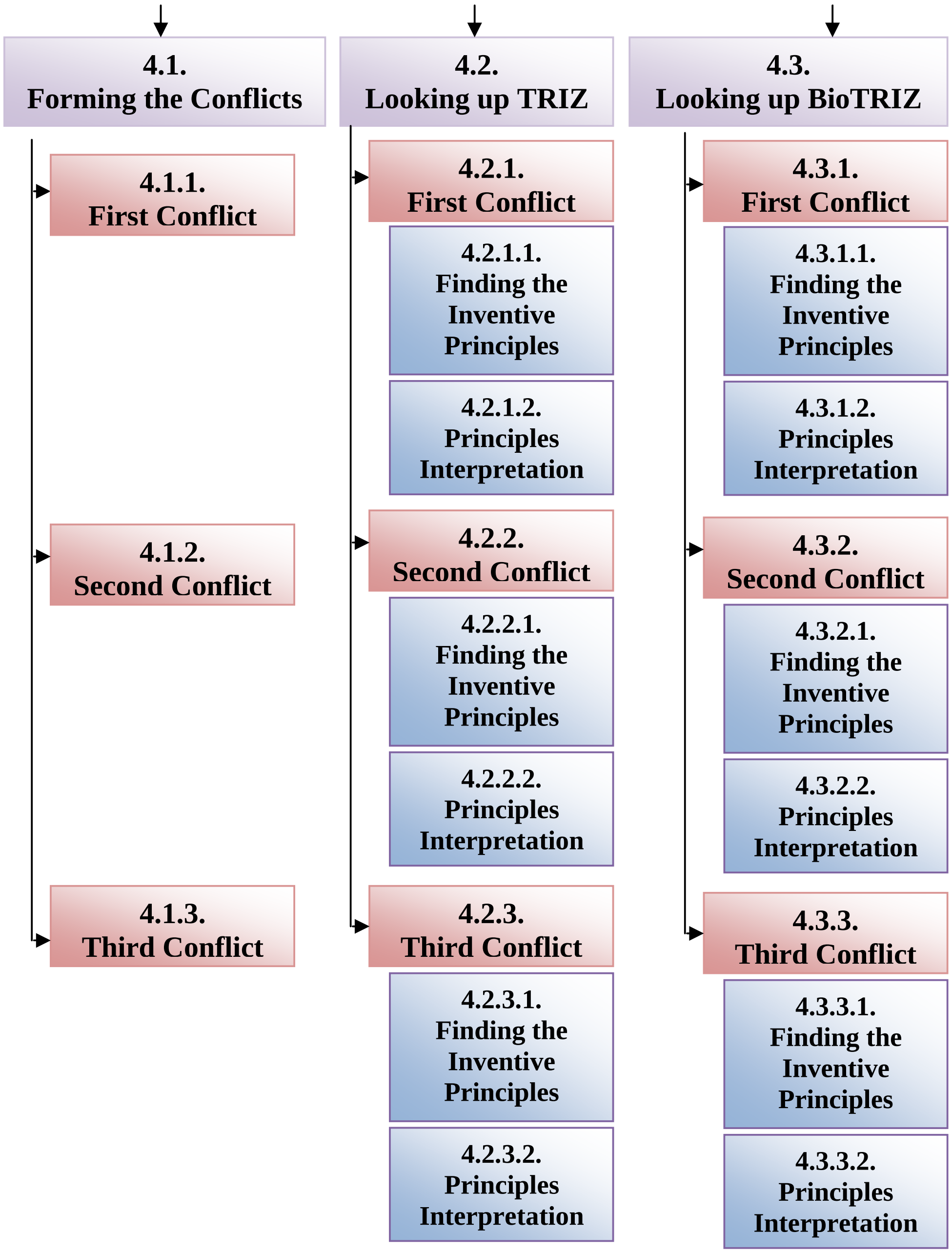
Chapter 4

APPLICATION TO BIOMIMETIC ARCHITECTURAL ENVIRONMENTAL DESIGN USING TRIZ AND BIOTRIZ

> *TRIZ is a tool for thinking,*
> *but not instead of thinking.*
> *…Genrich Altshuller*

Chapter 4

APPLICATION TO BIOMIMETIC ARCHITECTURAL ENVIRONMENTAL DESIGN USING TRIZ AND BIOTRIZ



Chapter 4

APPLICATION TO BIOMIMETIC ARCHITECTURAL ENVIRONMENTAL DESIGN USING TRIZ AND BIOTRIZ

Chapter Four

Application to Biomimetic Architectural Environmental Design Using TRIZ and BioTRIZ

In this chapter, TRIZ and BioTRIZ methods will be used to find a solution for an architectural environmental contradiction.

The proposed problem will be:
How can we regulate the heat gain through the building envelope?

After defining the problem, according to Vincent's biomimetic methodology (1), the next step will be:"*Analyze and understand the problem and so uncover the main conflicts or contradictions*".

The problem must be put in a contradiction form. The contradiction could be framed in the following question:
How can the envelope protect the internal space from the undesired heat/cold outside without being over heated/ cooled?

In this application, three different conflicts will be formed, looked up in both TRIZ and BioTRIZ matrices to extract the inventive principles recommended, and interpreted in the context of the proposed problem.

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(1) Previously reviewed in chapter three, at p. 138.

4.1. Forming the Conflicts:

4.1.1. First Conflict:

As presented before, the chosen design problem is:

“How can we regulate the heat gain through the building envelope?”

The formed contradiction is:

“How can the envelope protect the internal space from the undesired heat or cold outside without being overheated or overcooled?”

The contradiction here is between protecting the internal space by the envelope, and protecting the envelope itself, because the envelope itself, when overheated or overcooled, could be a harmful factor to the internal space.

Choosing the improving feature:

“Protecting the internal space” could be expressed by the feature “Stress” as an improving feature. This is because when the internal space is protected from heat or cold, there will be no “stress” on it. The feature”stress” here is an improving one.

Choosing the worsening feature:

“Protecting the envelope itself” could be so directly expressed by the feature “Object affected harmful”. The object, the envelope is affected harmful when it is overheated or overcooled. So, we have the following conflict:

(F 11) Stress × (F 30) Object affected harmful

4.1.2. Second Conflict:

The feature “Object generated harmful” can also express the previous problem framing, as the envelope, when overheated or overcooled, will gradually turn into a harmful factor affecting the internal space.

So, the second conflict will be:

(F 11) Stress × (F 31) Object generated harmful

4.1.3. Third Conflict:

In an attempt to form a different conflict or contradiction, the desired interior thermal comfort will be referred to by the feature “Temperature”, while the feature “Loss of energy” will express the unhelpful balancing or loss of useful energy that results from the heat gain through the building envelope (1). So, the third conflict will be:

(F 17) Temperature × (F 22) Loss of energy

After forming the conflicts the following step will be looking up these conflicts in TRIZ matrix.

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(1) In their research, Craig, S., et al., (2008a) used the feature “Loss of Energy to express undesired heat gain through the ceiling. The example was viewed at p. 144.

4.2. Looking up the Conflicts in TRIZ Matrix:

4.2.1. First Conflict:

4.2.1.1. Finding the Inventive Principles:

By looking up the conflict "Stress versus Object affected harmful" in TRIZ matrix shown in table (4-1), the procedure will be as follows:
Looking the feature: "stress" as an improving feature and the feature "Object affected harmful" as a worsening feature.

The row and column are hatched and the intersection that carries the solution is highlighted in blue.

From the matrix, it is found that the design principles that are suggested by TRIZ matrix to solve the contradiction: "Stress versus Object affected harmful" are:

- IP 22 Blessing in Disguise
- IP 2 Take Out
- IP 37 Thermal Expansion

4.2.1.2. Principles Interpretation:

The following step will be interpreting these principles in the field of Environmental architecture within the proposed problem context (1).

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(1) The principle explanation in the whole coming review will be copied from:
(www.triz40.com/aff_Principles.htm), and:
40 Inventive (Architecture) Principles with Examples for Darell Mann and Conall Ó Catháin at (www.triz-journal.com/archives/2001/07/b/index.htm),
While the principle interpretation reflects the researcher view of the solutions that the principle may suggest in this specific problem context.

Table (4-1) Looking up the three conflicts in TRIZ Contradiction Matrix : *Copied from (http://www.triz40.com/aff_Matrix.htm)*

			39 Worsening Features																																						
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
			1: Weight of moving object	2: Weight of stationary obj.	3: Length of moving obj.	4: Length of stationary obj.	5: Area of Moving Obj.	6: Area of stationary obj.	7: Volume of moving obj.	8: Volume of stationary obj.	9: Speed	10: Force (Intensity)	11: Stress or pressure	12: Shape	13: Stability of the object	14: Strength	15: Durability of moving obj.	16: Durability of non moving obj.	17: Temperature	18: Illumination intensity	19: Use of energy by moving obj.	20: Use of energy by stationary obj.	21: Power	22: Loss of Energy	23: Loss of substance	24: Loss of Information	25: Loss of Time	26: Quantity of substance	27: Reliability	28: Measurement accuracy	29: Manufacturing precision	30: Object-affected harmful	31: Object-generated harmful	32: Ease of manufacture	33: Ease of operation	34: Ease of repair	35: Adaptability or versatility	36: Device complexity	37: Difficulty of detecting	38: Extent of automation	39: Productivity
39 IMPROVING FEATURES	1	1: Weight of moving object	*	-	15 8 29 34	-	29 17 38 34	-	29 2 40 28	-	2 8 15 38	8 10 18 37	10 36 37 40	10 14 35 40	1 35 19 39	28 27 18 40	5 34 31 35	-	6 29 4 38	19 1 32	35 12 34 31	-	12 36 18 31	6 2 34 19	5 35 3 31	10 24 35	10 35 20 28	3 26 18 31	1 3 11 27	28 27 35 26	28 35 26 18	22 21 18 27	22 35 31 39	27 28 1 36	35 3 2 24	2 27 28 11	29 5 15 8	26 30 36 34	28 29 26 32	26 35 18 19	35 3 24 37
	2	2: Weight of stationary object	-	*	-	10 1 29 35	-	35 30 13 2	-	5 35 14 2	-	8 10 19 35	13 29 10 18	13 10 29 14	26 39 1 40	28 2 10 27	-	2 27 19 6	28 19 32 22	19 32 35	-	18 19 28 1	15 19 18 22	18 19 28 15	5 8 13 30	10 15 35	10 20 35 26	19 6 18 26	10 28 8 3	18 26 28	10 1 35 17	2 19 22 37	35 22 1 39	28 1 9	6 13 1 32	2 27 28 11	19 15 29	1 10 26 39	25 28 17 15	2 26 35	1 28 15 35
	3	3: Length of moving object	8 15 29 34	-	*	-	15 17 4	-	7 17 4 35	-	13 4 8	17 10 4	1 8 35	1 8 10 29	1 8 15 34	8 35 29 34	19	-	10 15 19	32	8 35 24	-	1 35	7 2 35 39	4 29 23 10	1 24	15 2 29	29 35	10 14 29 40	28 32 4	10 28 29 37	1 15 17 24	17 15	1 29 17	15 29 35 4	1 28 10	14 15 1 16	1 19 26 24	35 1 26 24	17 24 26 16	14 4 28 29
	4	4: Length of stationary obj.	-	35 28 40 29	-	*	-	17 7 10 40	-	35 8 2 14	-	28 10	1 14 35	13 14 15 7	39 37 35	15 14 28 26	-	1 10 35	3 35 38 18	3 25	-	-	12 8	6 28	10 28 24 35	24 26	30 29 14	-	15 29 28	32 28 3	2 32 10	1 18	-	15 17 27	2 25	3	1 35	1 26	26	..	30 14 7 26
	5	5: Area of Moving Object	2 17 29 4	-	14 15 18 4	-	*	-	7 14 17 4	-	29 30 4 34	19 30 35 2	10 15 36 28	5 34 29 4	11 2 13 39	3 15 40 14	6 3	-	2 15 16	15 32 19 13	19 32	-	19 10 32 18	15 17 30 26	10 35 2 39	30 26	26 4	29 30 6 13	29 9	26 28 32 3	2 32	22 33 28 1	17 2 18 39	13 1 26 24	15 17 13 16	15 13 10 1	15 30	14 1 13	2 36 26 18	14 30 28 23	10 26 34 2
	6	6: Area of stationary object	-	30 2 14 18	-	26 7 9 39	-	*	-	-	-	1 18 35 36	10 15 36 37	-	2 38	40	-	2 10 19 30	35 39 38	-	-	-	17 32	17 7 30	10 14 18 39	30 16	10 35 4 18	2 18 40 4	32 35 40 4	26 28 32 3	2 29 18 36	27 2 39 35	22 1 40	40 16	16 4	16	15 16	1 18 36	2 35 30 18	23	10 15 17 7
	7	7: Volume of moving object	2 26 29 40	-	1 7 4 35	-	1 7 4 17	-	*	-	29 4 38 34	15 35 36 37	6 35 36 37	1 15 29 4	28 10 1 39	9 14 15 7	6 35 4	-	34 39 10 18	2 13 10	35	-	35 6 13 18	7 15 13 16	36 39 34 10	2 22	2 6 34 10	29 30 7	14 1 40 11	25 26 28	25 28 2 16	22 21 27 35	17 2 40 1	29 1 40	15 13 30 12	10	15 29	26 1	29 26 4	35 34 16 24	10 6 2 34
	8	8: Volume of stationary obj.	-	35 10 19 14	19 14	35 8 2 14	-	-	-	*	-	2 18 37	24 35	7 2 35	34 28 35 40	9 14 17 15	-	35 34 38	35 6 4	-	-	-	30 6	-	10 39 35 34	-	35 16 32 18	35 3	2 35 16	-	35 10 25	34 39 19 27	30 18 35 4	35	-	1	-	1 31	2 17 26	-	35 37 10 2
	9	9: Speed	2 28 13 38	-	13 14 8	-	29 30 34	-	7 29 34	-	*	13 28 15 19	6 18 38 40	35 15 18 34	28 33 1 18	8 3 26 14	3 19 35 5	-	28 30 36 2	10 13 19	8 15 35 38	-	19 35 38 2	14 20 19 35	10 13 28 38	13 26	-	10 19 29 38	11 35 27 28	28 32 1 24	10 28 32 25	1 28 35 23	2 24 35 21	35 13 8 1	32 28 13 12	34 2 28 27	15 10 26	10 28 4 34	3 34 27 16	10 18	-
	10	10: Force (Intensity)	8 1 37 18	18 13 1 28	17 19 9 36	28 10	19 10 15	1 18 36 37	15 9 12 37	2 36 18 37	13 28 15 12	*	18 21 11	10 35 40 34	35 10 21	35 10 14 27	19 2	-	35 10 21	-	19 17 10	1 16 36 37	19 35 18 37	14 15	8 35 40 5	-	10 37 36	14 29 18 36	3 35 13 21	35 10 23 24	28 29 37 36	1 35 40 18	13 3 36 24	15 37 18 1	1 28 3 25	15 1 11	15 17 18 20	26 35 10 18	36 37 10 19	2 35	3 28 35 37
	11	11: Stress or pressure	10 36 37 40	13 29 10 18	35 10 36	35 1 14 16	10 15 36 28	10 15 36 37	6 35 10	35 24	6 35 36	36 35 21	*	35 4 15 10	35 33 2 40	9 18 3 40	19 3 27	-	35 39 19 2	-	14 24 10 37	-	10 35 14	2 36 25	10 36 3 37	-	37 36 4	10 14 36	10 13 19 35	6 28 25	3 35	22 2 37	2 33 27 18	1 35 16	11	2	35	19 1 35	2 36 37	35 24	10 14 35 37
	12	12: Shape	8 10 29 40	15 10 26 3	29 34 5 4	13 14 10 7	5 34 4 10	-	14 4 15 22	7 2 35	35 15 34 18	35 10 37 40	34 15 10 14	*	33 1 18 4	30 14 10 40	14 26 9 25	-	22 14 19 32	13 15 32	2 6 34 14	-	4 6 2	14	35 29 3 5	-	14 10 34 17	36 22	10 40 16	28 32 1	32 30 40	22 1 2 35	35 1	1 32 17 28	32 15 26	2 13 1	1 15 29	16 29 1 28	15 13 39	15 1 32	17 26 34 10
	13	13: Stability of the object	21 35 2 39	26 39 1 40	13 15 1 28	37	2 11 13	39	28 10 19 39	34 28 35 40	33 15 28 18	10 35 21 16	2 35 40	22 1 18 4	*	17 9 15	13 27 10 35	39 3 35 23	35 1 32	32 3 27 16	13 19	27 4 29 18	32 35 27 31	14 2 39 6	2 14 30 40	-	35 27	15 32 35	-	13	18	35 24 30 18	35 40 27 39	35 19	32 35 30	2 35 10 16	35 30 34 2	2 35 22 26	35 22 39 23	1 8 35	23 35 40 3
	14	14: Strength	1 8 40 15	40 26 27 1	1 15 8 35	15 14 28 26	3 34 40 29	9 40 28	10 15 14 7	9 14 17 15	8 13 26 14	10 18 3 14	10 3 18 40	10 30 35 40	13 17 35	*	27 3 26	-	30 10 40	35 19	19 35 10	35	10 26 35 28	35	35 28 31 40	-	29 3 28 10	29 10 27	11 3	3 27 16	3 27	18 35 37 1	15 35 22 2	11 3 10 32	32 40 25 2	27 11 3	15 3 32	2 13 25 28	27 3 15 40	15	29 35 10 14
	15	15: Durability of moving obj.	19 5 34 31	-	2 19 9	-	3 17 19	-	10 2 19 30	-	3 35 5	19 2 16	19 3 27	14 26 28 25	13 3 35	27 3 10	*	-	19 35 39	2 19 4 35	28 6 35 18	-	19 10 35 38	-	28 27 3 18	10	20 10 28 18	3 35 10 40	11 2 13	3	3 27 16 40	22 15 33 28	21 39 16 22	27 1 4	12 27	29 10 27	1 35 13	10 4 29 15	19 29 39 35	6 10	35 17 14 19
	16	16: Durability of non moving obj.	-	6 27 19 16	-	1 40 35	-	-	-	35 34 38	-	-	-	-	39 3 35 23	-	-	*	19 18 36 40	-	-	-	16	-	27 16 18 38	10	28 20 10 16	3 35 31	34 27 6 40	10 26 24	-	17 1 40 33	22	35 10	1	1	2	-	25 34 6 35	1	20 10 16 38
	17	17: Temperature	36 22 6 38	22 35 32	15 19 9	15 19 9	3 35 39 18	35 38	34 39 40 18	35 6 4	2 28 36 30	35 10 3 21	35 39 19 2	14 22 19 32	1 35 32	10 30 22 40	19 13 39	19 18 36 40	*	32 30 21 16	19 15 3 17	-	2 14 17 25	21 17 35 38	21 36 29 31	-	35 28 21 18	3 17 30 39	19 35 3 10	32 19 24	24	22 33 35 2	22 35 2 24	26 27	26 27	4 10 16	2 18 27	2 17 16	3 27 35 31	26 2 19 16	15 28 35
	18	18: Illumination intensity	19 1 32	2 35 32	19 32 16	-	19 32 26	-	2 13 10	-	10 13 19	26 19 6	-	32 30	32 3 27	35 19	2 19 6	-	32 35 19	*	32 1 19	32 35 1 15	32	13 16 1 6	13 1	1 6	19 1 26 17	1 19	-	11 15 32	3 32	15 19	35 19 32 39	19 35 28 26	28 26 19	15 17 13 16	15 1 19	6 32 13	32 15	2 26 10	2 25 16
	19	19: Use of energy by moving	12 18 28 31	-	12 28	-	15 19 25	-	35 13 18	-	8 35 35	16 26 21 2	23 14 25	12 2 29	19 13 17 24	5 19 9 35	28 35 6 18	-	19 24 3 14	2 15 19	*	-	6 19 37 18	12 22 15 24	35 24 18 5	-	35 38 19 18	34 23 16 18	19 21 11 27	3 1 32	-	1 35 6 27	2 35 6	28 26 30	19 35	1 15 17 28	15 17 13 16	2 29 27 28	35 38	32 2	12 28 35
	20	20: Use of energy by stationary	-	19 9 6 27	-	-	-	-	-	-	-	36 37	-	-	27 4 29 18	35	-	-	-	19 2 35 32	-	*	-	-	28 27 18 31	-	-	3 35 31	10 36 23	-	-	10 2 22 37	19 22 18	1 4	-	-	-	-	19 35 16 25	-	1 6
	21	21: Power	8 36 38 31	19 26 17 27	1 10 35 37	-	19 38	17 32 13 38	35 6 38	30 6 25	15 35 2	26 2 36 35	22 10 35	29 14 2 40	35 32 15 31	26 10 28	19 35 10 38	16	2 14 17 25	16 6 19	16 6 19 37	-	*	10 35 38	28 27 18 38	10 19	35 20 10 6	4 34 19	19 24 26 31	32 15 2	32 2	19 22 31 2	2 35 18	26 10 34	26 35 10	35 2 10 34	19 17 34	20 19 30 34	19 35 16	28 2 17	28 35 34
	22	22: Loss of Energy	15 6 19 28	19 6 18 9	7 2 6 13	6 38 7	15 26 17 30	17 7 30 18	7 18 23	7	16 35 38	36 38	-	-	14 2 39 6	26	-	-	19 38 7	1 13 32 15	-	-	3 38	*	35 27 2 37	19 10	10 18 32 7	7 18 25	11 10 35	32	-	21 22 35 2	21 35 2 22	-	35 32 1	2 19	-	7 23	35 3 15 23	2	28 10 29 35
	23	23: Loss of substance	35 6 23 40	35 6 22 32	14 29 10 39	10 28 24	35 2 10 31	10 18 39 31	1 29 30 36	3 39 18 31	10 13 28 38	14 15 18 40	3 36 37 10	29 35 3 5	2 14 30 40	35 28 31 40	28 27 3 18	27 16 18 38	21 36 39 31	1 6 13	35 18 24 5	28 27 12 31	28 27 18 38	35 27 2 31	*	-	15 18 35 10	6 3 10 24	10 29 39 35	16 34 31 28	35 10 24 31	33 22 30 40	10 1 34 29	15 34 33	32 28 2 24	2 35 34 27	15 10 2	35 10 28 24	35 18 10 13	35 10 18	28 35 10 23
	24	24: Loss of Information	10 24 35	10 35 5	1 26	26	30 26	30 16	-	2 22	26 32	-	-	-	-	-	10	10	-	19	-	-	10 19	19 10	-	*	24 26 28 32	24 28 35	10 28 23	-	-	22 10 1	10 21 22	32	27 22	-	-	-	35 33	35	13 23 15
	25	25: Loss of Time	10 20 37 35	10 20 26 5	15 2 29	30 24 14 5	26 4 5 16	10 35 17 4	2 5 34 10	35 16 32 18	-	10 37 36 5	37 36 4	4 10 34 17	35 3 22 5	29 3 28 18	20 10 28 18	28 20 10 16	35 29 21 18	1 19 26 17	35 38 19 18	1	35 20 10 6	10 5 18 32	35 18 10 39	24 26 28 32	*	35 38 18 16	10 30 4	24 34 28 32	24 26 28 18	35 18 34	35 22 18 39	35 28 34 4	4 28 10 34	32 1 10	35 28	6 29	18 28 32 10	24 28 35 30	-
	26	26: Quantity of substance	35 6 18 31	27 26 18 35	29 14 35 18	-	15 14 29	2 18 40 4	15 20 29	-	35 29 34 28	35 14 3	10 36 14 3	35 14	15 2 17 40	14 35 34 10	3 35 10 40	3 35 31	3 17 39	-	34 29 16 18	3 35 31	35	7 18 25	6 3 10 24	24 28 35	35 38 18 16	*	18 3 28 40	13 2 28	33 30	35 33 29 31	3 35 40 39	29 1 35 27	35 29 25 10	2 32 10 25	15 3 29	3 13 27 10	3 27 29 18	8 35	13 29 3 27
	27	27: Reliability	3 8 10 40	3 10 8 28	15 9 14 4	15 29 28 11	17 10 14 16	32 35 40 4	3 10 14 24	2 35 24	21 35 11 28	8 28 10 3	10 24 35 19	35 1 16 11	-	11 28	2 35 3 25	34 27 6 40	3 35 10	11 32 13	21 11 27 19	36 23	21 11 26 31	10 11 35	10 35 29 39	10 28	10 30 4	21 28 40 3	*	32 3 11 23	11 32 1	27 35 2 40	35 2 40 26	-	27 17 40	1 11	13 35 8 24	13 35 1	27 40 28	11 13 27	1 35 29 38
	28	28: Measurement accuracy	32 35 26 28	28 35 25 26	28 26 5 16	32 28 3 16	26 28 32 3	26 28 32 3	32 13 6	-	28 13 32 24	32 2	6 28 32	6 28 32	32 35 13	28 6 32	28 6 32	10 26 24	6 19 28 24	6 1 32	3 6 32	-	3 6 32	26 32 27	10 16 31 28	-	24 34 28 32	2 6 32	5 11 1 23	*	-	28 24 22 26	3 33 39 10	6 35 25 18	1 13 17 34	1 32 13 11	13 35 2	27 35 10 34	26 24 32 28	28 2 10 34	10 34 28 32
	29	29: Manufacturing precision	28 32 13 18	28 35 27 9	10 28 29 37	2 32 10	28 33 29 32	2 29 18 36	32 23 2	25 10 35	10 28 32	28 19 34 36	3 35	32 30 40	30 18	3 27	3 27 40	-	19 26	3 32	32 2	-	32 2	13 32 2	35 31 10 24	-	32 26 28 18	32 30	11 32 1	-	*	26 28 10 36	4 17 34 26	-	1 32 35 23	25 10	-	26 2 18	-	26 28 18 23	10 18 32 39
	30	30: Object-affected harmful	22 21 27 39	2 22 13 24	17 1 39 4	1 18	22 1 33 28	27 2 39 35	22 23 37 35	34 39 19 27	21 22 35 28	13 35 39 18	22 2 37	22 1 3 35	35 24 30 18	18 35 37 1	22 15 33 28	17 1 40 33	22 33 35 2	1 19 32 13	1 24 6 27	10 2 22 37	19 22 31 2	21 22 35 2	33 22 19 40	22 10 2	35 18 34	35 33 29 31	27 24 2 40	28 33 23 26	26 28 10 18	*	-	24 35 2	2 25 28 39	35 10 2	35 11 22 31	22 19 29 40	22 19 29 40	33 3 34	22 35 13 24
	31	31: Object-generated harmful	19 22 15 39	35 22 1 39	17 15 16 22	-	17 2 18 39	22 1 40	17 2 40	30 18 35 4	35 28 3 23	35 28 1 40	2 33 27 18	35 1	35 40 27 39	15 35 22 2	15 22 33 31	21 39 16 22	22 35 2 24	19 24 39 32	2 35 6	19 22 18	2 35 18	21 35 2 22	10 1 34	10 21 29	1 22	3 24 39 1	24 2 40 39	3 33 26	4 17 34 26	-	*	-	-	-	-	19 1 31	2 21 27 1	2	22 35 18 39
	32	32: Ease of manufacture	28 29 15 16	1 27 36 13	1 29 13 17	15 17 27	13 1 26 12	16 40	13 29 1 40	35	35 13 8 1	35 12	35 19 1 37	1 28 13 27	11 13 1	1 3 10 32	27 1 4	35 16	27 26 18	28 24 27 1	28 26 27 1	1 4	27 1 12 24	19 35	15 34 33	32 24 18 16	35 28 34 4	35 23 1 24	-	1 35 12 18	-	24 2	-	*	2 5 13 16	35 1 11 9	2 13 15	27 26 1	6 28 11 1	8 28 1	35 1 10 28
	33	33: Ease of operation	25 2 13 15	6 13 1 25	1 17 13 12	-	1 17 13 16	18 16 15 39	1 16 35 15	4 18 39 31	18 13 34	28 13 35	2 32 12	15 34 29 28	32 35 30	32 40 3 28	29 3 8 25	1 16 25	26 27 13	13 17 1 24	1 13 24	-	35 34 2 10	2 19 13	28 32 2 24	4 10 27 22	4 28 10 34	12 35	17 27 8 40	25 13 2 34	1 32 35 23	2 25 28 39	-	2 5 12	*	12 26 1 32	15 34 1 16	32 26 12 17	-	1 34 12 3	15 1 28
	34	34: Ease of repair	2 27 35 11	2 27 35 11	1 28 10 25	3 18 31	15 13 32	16 25	25 2 35 11	1	34 9	1 11 10	13	1 13 2 4	2 35	11 1 2 9	11 29 28 27	1	4 10	15 1 13	15 1 28 16	-	15 10 32 2	15 1 32 19	2 35 34 27	-	32 1 10 25	2 28 10 25	11 10 1 16	10 2 13	25 10	35 10 2 16	-	1 35 11 10	1 12 26 15	*	7 1 4 16	35 1 13 11	-	34 35 7 13	1 32 10
	35	35: Adaptability or versatility	1 6 15 8	19 15 29 16	35 1 29 2	1 35 16	35 30 29 7	15 16	15 35 29	-	35 10 14	15 17 20	35 16	15 37 1 8	35 30 14	35 3 32 6	13 1 35	2 16	27 2 3 35	6 22 26 1	19 35 29 13	-	19 1 29	18 15 1	15 10 2 13	-	35 28	3 35 15	35 13 8 24	35 5 1 10	-	35 11 32 31	-	1 13 31	15 34 1 16	1 16 7 4	*	15 29 37 28	1	27 34 35	35 28 6 37
	36	36: Device complexity	26 30 34 36	2 26 35 39	1 19 26 24	26	14 1 13 16	6 36	34 26 6	1 16	34 10 28	26 16	19 1 35	29 13 28 15	2 22 17 19	2 13 28	10 4 28 15	-	2 17 13	24 17 13	27 2 29 28	-	20 19 30 34	10 35 13 2	35 10 28 29	-	6 29	13 3 27 10	13 35 1	2 26 10 34	26 24 32	22 19 29 40	19 1	27 26 1 13	27 9 26 24	1 13	29 15 28 37	*	15 10 37 28	15 1 24	12 17 28
	37	37: Difficulty of detecting	27 26 28 13	6 13 28 1	16 17 26 24	26	2 13 18 17	2 39 30 16	29 1 4 16	2 18 26 31	3 4 16 35	30 28 40 19	35 36 37 32	27 13 1 39	11 22 39 30	27 3 15 28	19 29 39 25	25 34 6 35	3 27 35 16	2 24 26	35 38	19 35 16	18 1 16 10	35 3 15 19	1 18 10 24	35 33 27 22	18 28 32 9	3 27 29 18	27 40 28 8	26 24 32 28	-	22 19 29 28	2 21	5 28 11 29	2 5	12 26	1 15	15 10 37 28	*	34 21	35 18
	38	38: Extent of automation	28 26 18 35	28 26 35 10	14 13 17 28	23	17 14 13	-	35 13 16	-	28 10	2 35	13 35	15 32 1 13	18 1	25 13	6 9	-	26 2 19	8 32 19	2 32 13	-	28 2 27	23 28	35 10 18 5	35 33	24 28 35 30	35 13	11 27 32	28 26 10 34	28 26 18 23	2 33	2	1 26 13	1 12 34 3	1 35 13	27 4 1 35	15 24 10	34 27 25	*	5 12 35 26
	39	39: Productivity	35 26 24 37	28 27 15 3	18 4 28 38	30 7 14 26	10 26 34 31	10 35 17 7	2 6 34 10	35 37 10 2	-	28 15 10 36	10 37 14	14 10 34 40	35 3 22 39	29 28 10 18	35 10 2 18	20 10 16 38	35 21 28 10	26 17 19 1	35 10 38 19	1	35 20 10	28 10 29 35	28 10 35 23	13 15 23	-	35 38	1 35 10 38	1 10 34 28	18 10 32 1	22 35 13 24	35 22 18 39	35 28 2 24	1 28 7 10	1 32 10 25	1 35 28 37	12 17 28 24	35 18 27 2	5 12 35 26	*

IP 22 Blessing in disguise:

Principle Explanation:

- *Use harmful factors (particularly, harmful effects of the environment or surroundings) to achieve a positive effect.*
- *Amplify a harmful factor to such a degree that it is no longer harmful.*

Principle Interpretation:

1- **Use heat to generate power:**

Using photovoltaic cells and other systems like "SolarWall" and "SolarWall PV/T", which is a combination of the Solar Wall, shown in Fig. (4-1), with solar photovoltaic panels, to produce both solar preheated air and electricity at the same time.

The new technology was used in the roof of one of the central buildings in the Olympic village of Beijing, which is used as a service center for the athletes during the Olympics (1), shown in Fig. (4-2).

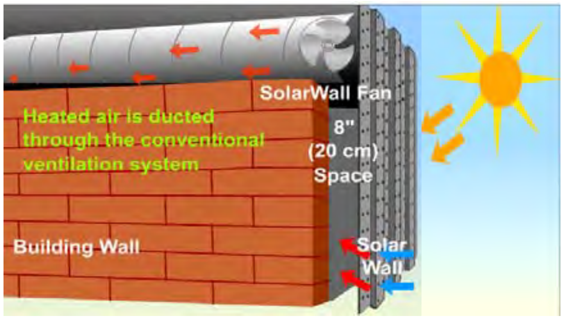

Figure (4-1)
Conventional Solar Wall Technology.
(www.solarwall.com)

Figure (4-2) Solar Wall PV/T
in Beijing Olympic Village
(www.solarwall.com/posts/first-of-its-kind-hybrid-solarwall-pvt-system-in-olympic-village60.php)

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(1) www.Solarwall.com

IP 2 Take Out (Removal/Extraction):

Principle Explanation:

- *Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.*

Principle Interpretation:

1. **Let light pass but not heat:**

Light pipes could be used to separate the hot light source from the location where light is needed (1). In another word, it means to separate heat, as an unwanted factor, from the sun ray that enters the building, or to single out the light as a necessary part.

Solar light pipe may perform this function as it transports light and still offers better heat insulation properties.

Solar light pipe is given a number of names like sun tunnels, sun pipes, sun scopes, light tube, or daylight pipes (2). Fig. (4-3a) illustrates the concept.

California Academy of Science is an example for extracting light through certain points and keeping the whole roof naturally insulated with 15cm of soil. Fig. (4-3b) shows exterior and interior of the building (3).

2. **Let light pass but not air:**

In Wekalet El Kharroub in Egypt (4), the wind catcher is closed at winter with a transparent shelf that enables light to pass but not the air, as shown in Fig. (4-4).

---

(1) The interpretation is copied from (http://www.triz40.com/aff_Principles.htm).
(2) www.en.wikipedia.org
(3) Another example is the chimney of Wekalet El Kharroub. It will be mentioned at p. 164
(4) Designed by Prof. Dr. Baha'a Bakry.

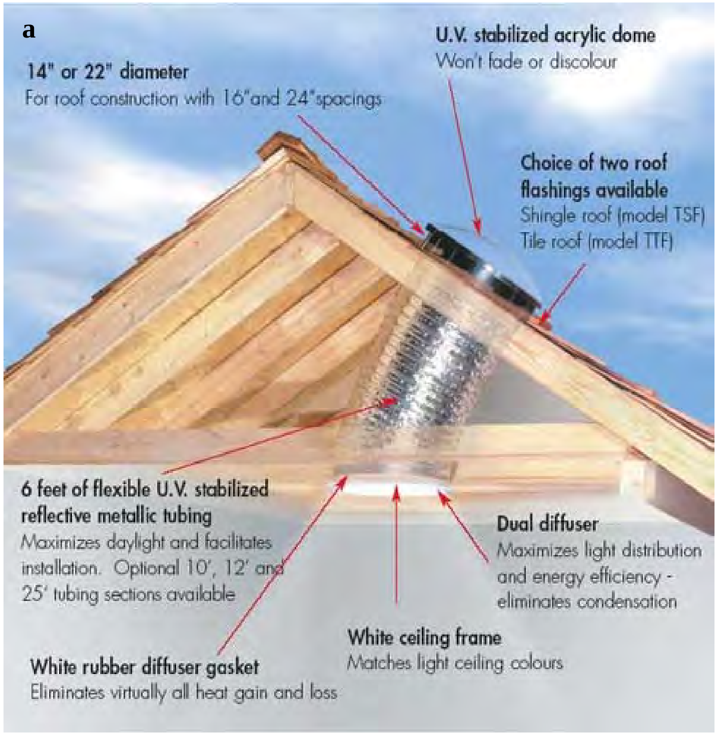

Figure (4-3) Separating Light from Heat.

a. Solar light Pipe.

(http://www.cbsenergy.co.uk/suntunnel.html)

b. California Academy of Sciences Exterior and Interior.

(http://www.robaid.com/tech/green-architecture-california-academy-of-sciences.htm)

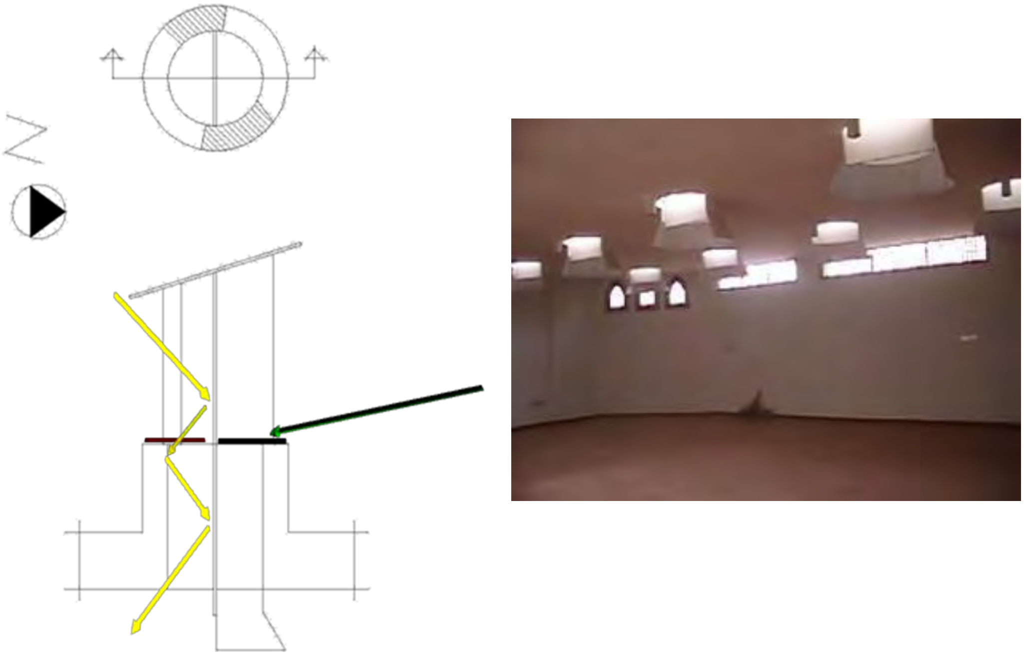

Figure (4-4) Wind Catcher in Wekalet El Kharroub
Left: Section, Right: Interior View
(By El far et al., in team work research-
Preliminary Master Courses-Cairo University-2007)

1. Let air pass but not heat:

In the conference hall of Wekalet El Kharroub, a wind catcher and a chimney offers the continuity of a ventilation process, and yet prevents the interior from the outside heat.

It is also noticed that the chimney was painted black from the outside, and white from the inside. This generates differences in pressure and facilitates air movement along the chimney.

The chimney also solves the conflict "Let light pass but not heat", as the outline of the chimney was designed according to the sun path diagram in Cairo city, in order to prevent the penetration of direct sun rays, and allow the multi reflections of day light according to the different angles of deflection from sun positions along the year.
Fig. (4-5) illustrates the building.

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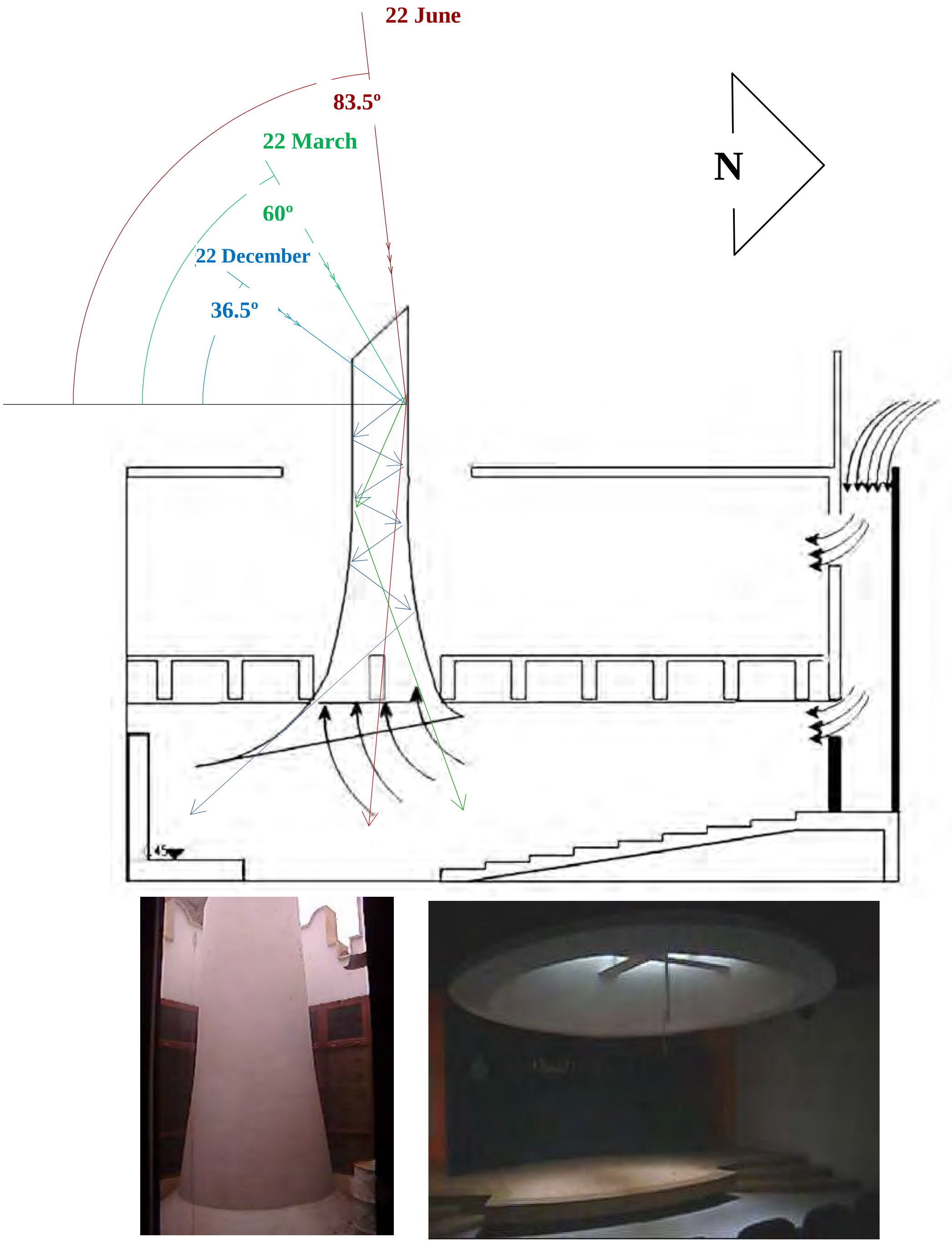

Figure (4-5)
Chimney and Wind Catcher in the Conference Hall of Wekalet El Kharroub
Up: Section,
Down Left: The Chimney Body at the Upper Floor, "Not Yet Painted Black".
Down Right: The Chimney inside the Conference Hall
(By El far et al., in team work research-
Preliminary Master Courses-Cairo University-2007)

IP 37 Thermal Expansions:

Principle Explanation:

- *Use thermal expansion, or contraction of materials.*
- *If thermal expansion is being used, use multiple materials with different coefficients of thermal expansion.*

Principle Interpretation:

Bi-metallic hinges (1) offer self-opening windows/ventilators in order to regulate climate inside building.

4.2.2. Second Conflict:

4.2.2.1. Finding the Inventive Principles:

To solve the conflict between “Stress” and “Object generated harmful”, the conflict is looked up in TRIZ matrix that is shown in table (4-1) (2).

The intersection between the “Stress” row and the “Object generated harmful” column is highlighted in yellow.

So, the inventive principles that solve the conflict between “stress” and “object generated harmful” are:

- IP 2 Take Out
- IP 33 Homogeneity
- IP 27 Cheap Disposable
- IP 18 Mechanical Vibration.

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(1) The idea was previously illustrated at p. 66.
The interpretation is copied from Mann and Catháin
at (www.triz-journal.com/archives/2001/07/b/index.htm),

(2) Viewed at p. 160.

4.2.2.2. Principles Interpretation:

The inventive principle “Take Out” was previously interpreted in the first conflict, so the interpretation here will start from IP 33 “Homogeneity”.

<u>IP 33 Homogeneity:</u>

Principle Explanation:

- *Make objects interacting with a given object of the same material (or material with identical properties).*

Principle Interpretation:

1. **<u>Building with the same material of the environment:</u>**

The example here is the snow dome or the Igloo that is made from ice, shown in Fig. (4-6a)

2. **<u>Building with clay as it is the same material of human body:</u>**

It is claimed that building spaces with clay is the best for matching humans who live inside.

> *“The use of the clay in building or finishing processes gives the space physical, chemical and thermal properties that harmonize with the properties of human body, which has identical components of clay.*
>
> *It could be said that there is a relation of resonance between human body and clay, that relation facilitates the exchange of influences between them, and creates a sense of total comfort. That relation of resonance is not yet scientifically explored.* (1)”

Fig. (4-6b) shows Kaédi Hospital in Mauritania (2).

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(1) Abdoun, A., (2007), “Design by Solar Radiation as a Tool for Control on the Ambiance Energy of Architectural Spaces”.

(2) Designed by Abrizio Caroloa and Irahim Niang.

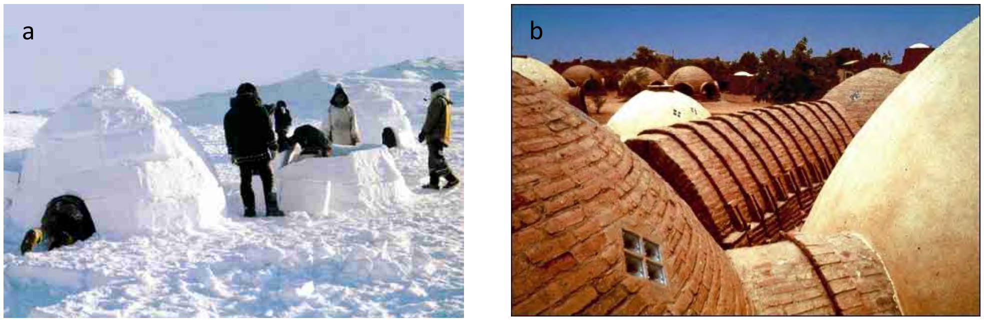

Figure (4-6) Homogeneity.

a. Homogeneity between Building Materials and Environment in the Igloo *(http://www.starchak.ca/personal/personal.htm)*

b. Homogeneity between Building Materials and Occupants in Kaédi Hospital in Mauritania *(http://lexicorient.com/mauritania/kaedi.htm)*

IP 27 Cheap Disposable:

Principle Explanation:

- *Replace an inexpensive object with a multiple of inexpensive objects, comprising certain qualities (such as service life, for instance).*

Principle Interpretation:

It was difficult to find interpretation for this principle, in the context of the proposed problem.

IP 18 Mechanical Vibration:

Principle Explanation:

- *Cause an object to oscillate or vibrate.*
- *Increase its frequency (even up to the ultrasonic).*
- *Use an object's resonant frequency.*

Principle Interpretation:

It was difficult to find interpretation for this principle, in the context of the proposed problem.

4.2.3. Third Conflict:

4.2.3.1. Finding the Inventive Principles:

By looking up the conflict “Temperature” versus “Loss of Energy” in TRIZ matrix (1), the procedure will be looking the feature: “Temperature” as an improving feature and the feature ”Loss of Energy” as a worsening feature.

The intersection between the “Temperature” row and the “Loss of Energy” column is highlighted in green.

The following design principles will be suggested to solve this contradiction:

IP 17 Another Dimension
IP 21 Skipping
IP 35 Parameter changes
IP 38 Strong oxidants

4.2.3.2. Principles Interpretation:

The following step will be interpreting these principles in the field of Environmental architecture within the proposed problem context.

IP 17 Another Dimension:

Principle Explanation:

- *To move an object in two- or three-dimensional space.*
- *Use a multi-story arrangement of objects instead of a single-story arrangement.*
- *Tilt or re-orient the object, lay it on its side.*
- *Use 'another side' of a given area.*

---

(1) Table (4-1), shown at p. 160.

Principle Interpretation:

1- **<u>Tilt walls and roofs to protect them from the sun:</u>**

The use of Pyramidal spaces, for example, achieves the least heat transfer through the ceiling, where the ceiling area equals zero. Also walls may be tilted to be protected from direct exposure to the sun.

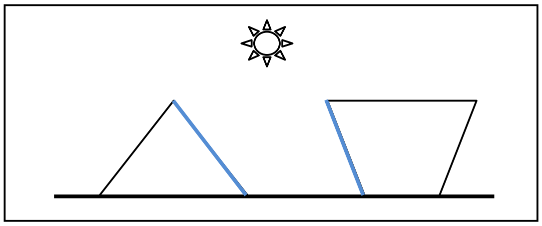

Figure (4-7) Tilted Walls and Roofs.
(By researcher)

2- **<u>Vertically Assembled building blocks offers protection from the sun and harsh climate:</u>**

The second explanation of the principle" Use multi storey arrangements" guides to the idea of reducing the exposed envelope of buildings by assembling them in one high rise building.

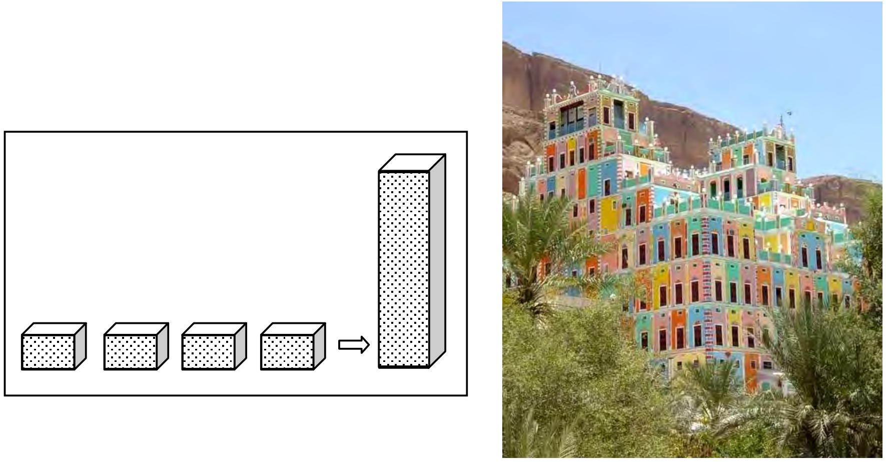

Figure (4-8) Multistory Arrangements Reduce Exposed Envelope Area.
Left: Sketch showing the reduced roof area in case of multistory arrangement
(By researcher)
Right: Multistorey Vernacular Building in Yemen
(http://whitetriangle.wordpress.com/category/architecture/)

IP 21 Skipping:

Principle Explanation:

- *Conduct a process, or certain stages (e.g. destructible, harmful or hazardous operations) at high speed.*

Principle Interpretation:

It was difficult to find interpretation for this principle, in the context of the proposed problem.

IP 35 Parameter changes:

Principle Explanation:

- *Change an object's physical state (e.g. to a gas, liquid, or solid.)*
- *Change the concentration or consistency*.
- *Change the degree of flexibility***.**
- *Change the temperature.*

Principle Interpretation:

1. **Foam insulators:**

   The use of foam insulators achieves flexibility in filling irregular wall cavities.

IP 38 Strong oxidants:

Principle Explanation:

- *Replace common air with oxygen-enriched air.*
- *Replace enriched air with pure oxygen.*
- *Expose air or oxygen to ionizing radiation.*
- *Use ionized oxygen.*
- *Replace ionized oxygen with ozone.*

Principle Interpretation:

It was difficult to find interpretation for this principle, in the context of the proposed problem.

4.3. Looking up the Conflicts in BioTRIZ Matrix:

4.3.1. First and Second Conflicts:

4.3.1.1. Turning from TRIZ to BioTRIZ Features

The next step will be transforming each of the selected features (F11) and (F30) that belong to the 39 features of TRIZ matrix, into one of the BioTRIZ six categories or features. This step is performed by looking up table (4-2) that views the relation between TRIZ and BioTRIZ features. The shading parts illustrate the BioTRIZ features equivalent to the contradicting TRIZ features in our conflict.

From table (4-2) we conclude that our BioTRIZ conflict will be:

Energy versus Information.

We notice here that both features ”Object generated harmful” and “Object affected harmful” lie in the BioTRIZ category “ Information”. So for both TRIZ conflicts, the BioTRIZ conflicts will be the same.

Table (4-2): Distribution of Altshuller's Conflict Features to the BioTRIZ Categories (1)

Looking up "Stress versus Object affected and/or generated harmful" conflict:

Operational Field and its Meaning	Contradicting Parameters or Features	Operational Field and its Meaning	Contradicting Parameters or Features
1- **Substance** Add, remove or change properties of a material.	▪ Weight of moving and stationary object (1,2) ▪ Loss of substance (23) ▪ Quantity of substance (26)	**4-** **Time** Change speed of process or order of actions	▪ Speed (9) ▪ Duration of action of moving and stationary object (15, 16) ▪ Loss of time (25) ▪ Productivity (39)
2- **Structure** Add, remove or Regroup structural parts	▪ Stability of the object's composition (13) ▪ Manufacturing precision(29) ▪ Ease of manufacture (32) ▪ Device complexity (36)	**5-** **Energy** Change energy source or field	▪ Total force (10) ▪ **Stress or pressure (11)** ▪ Strength (14) ▪ Temperature (17) ▪ Illumination intensity (18) ▪ Use of energy by moving and stationary object (19, 20) ▪ Power (21) ▪ Loss of energy (22)
3- **Space** Change position or shape of system or parts	▪ Length of moving and stationary object (3, 4) ▪ Area of moving and stationary object (5, 6) ▪ Volume of moving and stationary object (7, 8) ▪ Shape (12)	**6-** **Information** Change interactions or regulation of a system or its elements	▪ Loss of information (24) ▪ Reliability (27) ▪ Measurement accuracy (28) ▪ **Object-affected and object-generated harmful factors (30, 31)** ▪ Ease of operation and repair (33, 34) ▪ Adaptability or versatility (35) ▪ Difficulty of detecting and measuring (37, 38)

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(1) Formed according to Vincent, J., et al., "Biomimetics: Its Practice and Theory, Appendix 2, p. 11.

4.3.1.2. Finding the inventive Principles:

The next step will be looking up this conflict in BioTRIZ matrix, which is viewed in table (4-3) to extract the inventive principles recommended to solve the conflict.

Table (4-3): BioTRIZ Matrix (1)
Looking Up “Energy versus Information" Conflict

	Substance	Structure	Space	Time	Energy	Information
Substance	13-15-17 20-31-40	1-3-15 24-26	1-5 13-15 3	15 19 27 29 30	3-6-9 25-31 35	3-25-26
Structure	1-10-15 19	1-15-19 24-34	10	1-2 4	1-2-4	1-3-4-15-19 24 25-35
Space	3-14-15 25	2-5-10 15-19	4-5 36-14 17	1-19 29	1-3-4 15-19	3-15-21-24
Time	1-3-15 20 25-38	1-4-6 15-17-19	1-4-7 38	2-3 11 20 26	3-9-15 20-22 25	1-3-10 19 23
Energy	1-3-13 14-17-25 31	1-3-5 6-25-35 36-40	1-3-4 15-25	3-10 23 25 35	3-5-9 22-25 32-37	**1-3-4 15-16-25**
Information	1-6-22	1-3-6 18-22 24-32 34-40	3-20 22-25 33	2-3 9-17 22	1-3-6 22-32	3-10-16 23 25

The shading parts illustrate looking up the contradiction between “Stress” (an Energy feature) and “Object generated harmful” (an information feature).

---

(1) Copied from: Vincent, J., et al., "Biomimetics: Its Practice and Theory", p.477.

By looking up the BioTRIZ matrix, in table (4-3), we can conclude that the inventive principles recommended to solve this conflict are:

IP 1 Segmentation
IP 3 Local quality
IP 4 Asymmetry
IP 15 Dynamics
IP 16 Partial or excessive actions
IP 25 Self service.

4.3.1.3. Principles Interpretation:

The following step will be interpreting these principles in the field of Environmental architecture within the proposed problem context.

IP 1 Segmentation :

Principle Explanation:

- *Divide an object into independent parts; make it sectional or able to be dismantled. Increase the degree of fragmentation and segmentation.*
- *Make an object easy to assemble or disassemble.*
- *Increase the degree of fragmentation or segmentation.*

Principle Interpretation:

1. **Segmentation between Solid and Void.**

Windows are independent parts. Fig. (4-9) illustrates significant distribution of windows in the Zollverein School of Management and Design in Germany, designed by Kazuyo Sejima and Ryue Nishizawa with SANAA Architects.

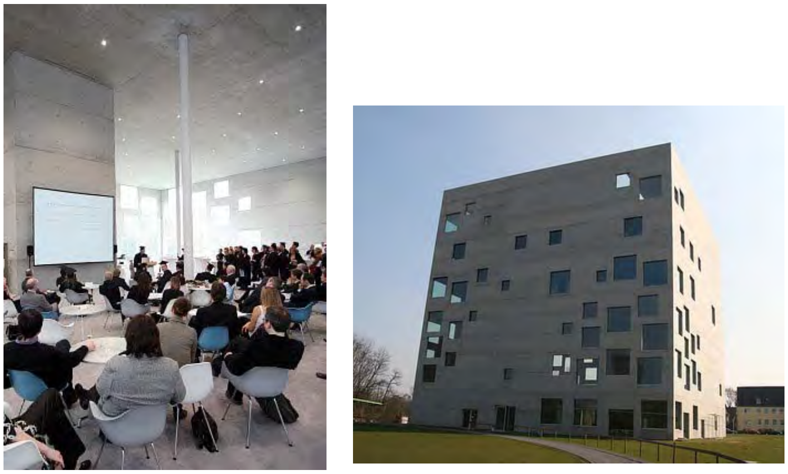

Figure (4-9) Zollverein School of Management and Design.
Left: Exterior.(www.architecturerevived.blogspot.com/2008/12/zollverein-school-of-management-and.html)
Right: Interior. (www. zollverein-school.de/index.htm)

Defining the surface as segmented into Independent parts of solids and voids allows the architect to choose the best place for his openings, according to the environmental and occupants' needs.

This approach is much more environmentally effective compared to the use of glass curtain walls.

2. Segmentation of Surface:

Cladding units and Ceramics with non uniform surface, as in the following Examples:

- Sierchuck house in Argentina by Justo Solsona. The tile roof continues down as a wall (1). Fig. (4-10) shows how the simple idea provided a great amount of shading on the façade.
- National Space Centre Exhibition and Research Complex, in England, designed by Grimshaw Architects (2), shown in Fig (4-11).

Figure (4-10) Sierchuck House, Argentina.
(Bullrich, 1969)

Figure (4-11) National Space Centre Exhibition and Research Complex.
(www.caa.uidaho.edu/arch504ukgreenarch/CaseStudies/SpaceCentre2.pdf)

3. Segmentation of Shape:

The building could have a segmented profile in order to provide shading. This could be divided into two types:

- Integrated Segmentation: in Pusat Tenaga Malaysia or Malaysia Energy Center, designed by Ruslan Khaled (3) shown in Fig. (4-12).
- Differential Segmentation: in The Architecture Centre Amsterdam (ARCAM) in Netherland, designed by René van Zuuk, shown in Fig. (4-13).

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(1) Bullrich, F., “New Directions in Latin American Architecture”.
(2) www.caa.uidaho.edu/arch504ukgreenarch/CaseStudies/SpaceCentre2.pdf
(3) www.futurarc.com/previous_edition/zeroenergy.cfm

The zinc-coated aluminum strips form a continuous plane curling itself all around the building mass (1).

Figure (4-12) Self Shading by Segmented Profile in Pusat Tenga Malaysia
(www.futurarc.com/previous_edition/zeroenergy.cfm)

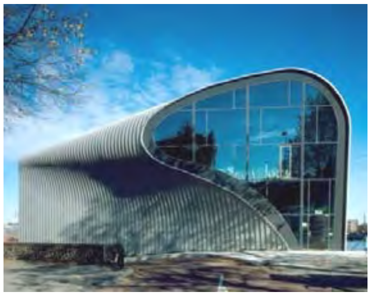

Figure (4-13) Self Shading by Segmented Profile in the Architecture Centre Amsterdam (ARCAM) in Netherland.
(www.archdaily.com/15091/arcam-rene-van-zuuk-architekten)

4. Segmentation of Shade and Shadow:

Telephonica building in Madrid, designed by Rafael de La-Hoz Castanys (2), shown in Fig. (4-14) exemplifies the segmented shadow. The concept can be applied to cover specific desired parts of the façade.

Figure (4-14) Telephonica Building in Madrid
(Left) www.e-architect.co.uk/madrid/telefonica_buildings.htm
(Right) www.inhabitat.com/2009/05/21/madrids-distrito-c-self-shading-office/

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(1) www.archdaily.com/15091/arcam-rene-van-zuuk-architekten
(2) www.e-architect.co.uk/madrid/telefonica_buildings.htm

5. **Segmentation of Color:**

Since colors vary in their thermal capacities, the segmentation of a plane into different colors may result in variable amounts of thermal gain.

6. **Segmentation of Material:**

We can turn the envelope into segmented parts with different building and/or finishing materials. Since materials vary in their thermal properties, the concept of segmentation may serve the design solution, instead of dealing with the envelope as one unit of a single material with specific properties.

7. **Segmentation of Layers:**

- Divide the outer skin into segmented layer that provide shading. Fig. (4-15) shows Putrajay towers in Malaysia.
- Divide the envelope into double layered envelope to produce air movement to cool the window wall as in 0-14 tower, Dubai, shown in Fig. (4-16).

Figure (4-15) Putrajay Towers in Malaysia
(Elnimeiri and Gupta, 2008)

Figure (4-16) 0-14 Tower, Dubai.
(www.e-architect.co.uk/dubai/jpgs/o14_tower_dubai_rur011008_2.jpg)

IP 3 Local quality:

Principle Explanation:

- *Change an object's structure, action, environmental, or external influence/impact from uniform to non uniform.*
- *Make each part of an object functions in condition most suitable for its operation; make each part of an object fulfill a different and/or complementary useful function.*

According to Vincent et al., (1) each internal organ in an animal has its own micro-environment, often surrounding itself with a membrane to emphasize this separation.

Principle Interpretation:

1- <u>Applying non uniform surface to provide shading.</u>

It is the same recommendation of second interpretation of IP 1 "Segmentation of Surface", shown in Figs. (4-10) and (4-11) (2)

2- <u>Applying multi component skin facades in which each layer fulfils different function.</u>

The Active Wall of the UCB Center (3) is composed of an external double glazed, mechanically ventilated cavity and a clear single layer internal glazing. Motorized blinds are positioned in the ventilated cavity and controlled depending on the solar iridescence (4).

As a result, the double skin façade fulfils a set of functions include vision, insulation, ventilation and shading. Fig. (4-17) illustrates the UCB center.

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(1) Vincent, J., et al., "Biomimetics: Its Practice and Theory". Appendix 1, p. 2.
(2) Shown at p. 177.
(3) Designed by Bureau Assar
(www.bbri.be/activefacades/new/index.cfm?cat=5_example_building&sub=3_belgium)
(4) Kragh, M., "Monitoring of Advanced Facades and Environmental Systems".

Figure (4-17) UCB Center.
Up: Drawing of the Mass.
Middle: View of the Building.
Down: View within the Doubled Façade.
(Mikolajczak, 2000)

IP 4 Asymmetry:

Principle explanation:

- *Change the shape or properties of an object from symmetrical to asymmetrical.*
- *Change the shape of an object to suit external asymmetries (e.g. ergonomic features.)*

According to Vincent et al., (1) very few biological objects are symmetrical. The asymmetry represents an immediately adaptive and efficient response to function.

Principle interpretation:

1-Assemetry in form:

The city Hall in London leans back towards the south, where floor plates are stepped inwards from top to bottom, providing natural shading from the most intense direct sunlight (2) as shown in Fig. (4-18)

Figure (4-18) City Hall.
(http://www.artofthestate.co.uk/photos/london_city_hall.jpg)

2- Asymmetry to serve aerodynamically.

- The asymmetry in openings distribution in section, shown in Fig. (4-19), creates air movement and forces the hotter air to exit the space.

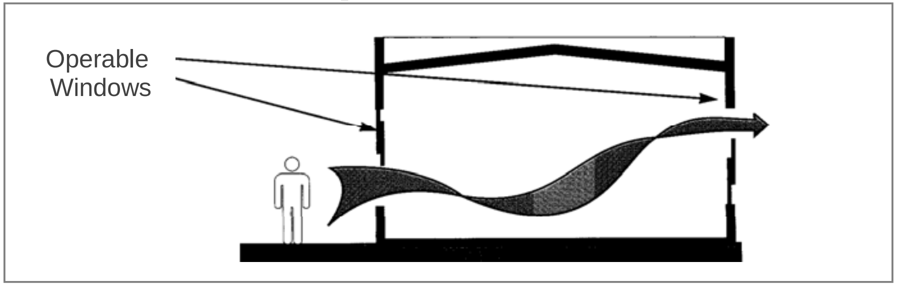

Figure (4-19) Cross Ventilation
Due to the Unsymmetrical Distribution of Openings
(Passive Solar Handbook: Introduction to Passive Solar Concepts, United States Air Force. (www.wbdg.org/ccb/AF/AFH/pshbk_v1.pdf)

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(1) Vincent, J., et al., "Biomimetics: its practice and theory", appendix 1, p. 2.
(2) www.london.gov.uk/gla/city_hall/city_hall_green.jsp

- The asymmetry in the section of the opening itself increases the air velocity, like the windows found in Wekalet Bazaraa shown in Fig. (4-20).

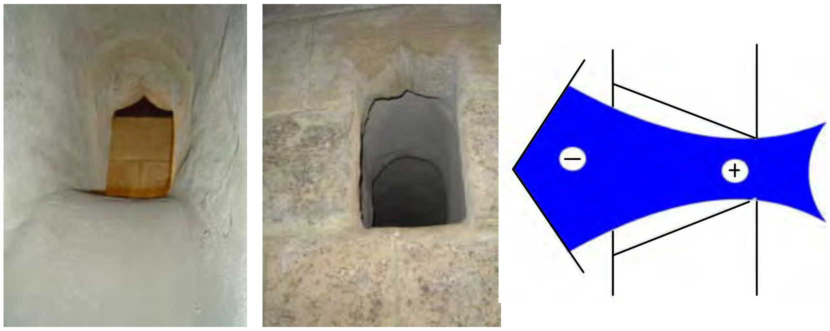

Figure (4-20) Asymmetry in the Section of the Opening of Wekalet Bazaraa
Left: Inside.
Middle: Outside.
Right: Direction of Air Movement.
(By the researcher and others in team work research-Preliminary master courses-Cairo university-2007)

- The asymmetry in the width of the corridors in Wekalet Bazaraa increases the air velocity. Fig. (4-21).

This may not concern the building envelope but the same treatment may be applied in case of the doubled layer envelope, where the space between the layers may be asymmetrical, and hence the air velocity increases and results in more heat loss.

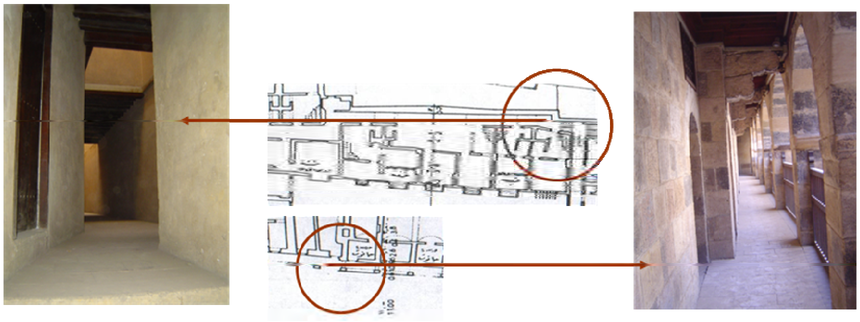

Figure (4-21) Asymmetry in Corridors Section of Wekalet Bazaraa.
(By researcher and others in team work research-Preliminary master courses-Cairo university-2007)

<u>3-Assemetry in sun breakers orientation to provide a better shading:</u>

In USEK Student Housing in Lebanon, designen by Henry Eid, the asymmetrical framed windows, evoking fins, indicate the organization of the students' rooms (1).

Instead of respecting the organization of the students'room, as shown in Fig.(4-22), the cantilever window frames should have been designed according to the sun directions to achieve maximum shading.

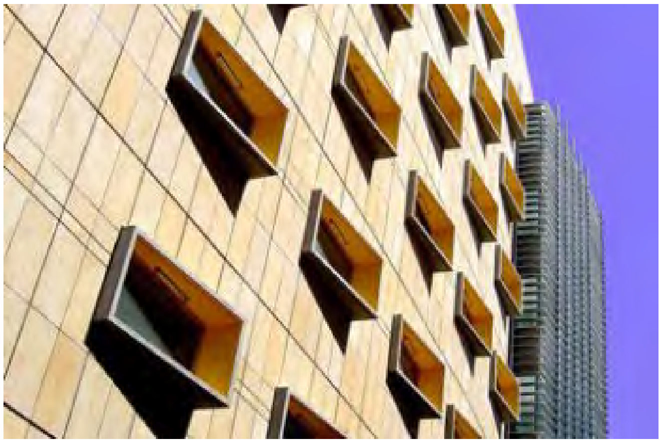

Figure (4-22) Assymetry in Sun Breakers Orientation in USEK Student Housing in Lebanon
(www.egodesign.ca/en/article.php?article_id=244&page=3)

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(1) www.egodesign.ca/en/article.php?article_id=244&page=3

IP 15 Dynamics

Principle explanation:

- *Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.*
- *Divide an object into parts capable of movement relative to each other.*
- *If an object (or process) is rigid or inflexible, make it movable or adaptive.*
- *Increase the degree of free motion*

Principle interpretation:

1- Movable spaces:

The idea of dynamic architecture or rotating towers, shown in Fig. (4-23), was so far, used for luxury. It is believed that it could also be used to serve as an environmental design tool. For example, Bedrooms could face the east at early morning, and then move to face the north at midday.

Figure (4-23) Rotating Tower in Dubai by David Fisher
Left: (www.inhabitat.com/2007/05/16/david-fishers-twirling-wind-power-tower/)
Right: (www.dynamicarchitecture.net/home.html)

2- Aerodynamic strategies:

Adopt design strategies that allow the air movement on the surface of the building envelope (1).

It is believed that the design of dancing towers helps the air currents to move on the building surface rapidly. Fig.(4-24) shows Dubai towers, an example of dancing towers.

Figure (4-24) Dubai Towers
(Elnimeiri, 2008)

Elnimeiri states that the wind pressure is conservatively increased by considering the potential dynamic effects due to the unique geometry of the tower (2).

The profile in Fig. (4-25) shows 1.44kPa (30psf) at the ground, and 3.35kPa (70psf) at 440 m high.

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(1) This concludes a set of design strategies, like those mentioned in the IP Asymmetry (No.2): Asymmetry to serve aerodynamically, at p. 182.

(2) Elnimeiri, M., “Dubai Tower 29, Structure and Form”.

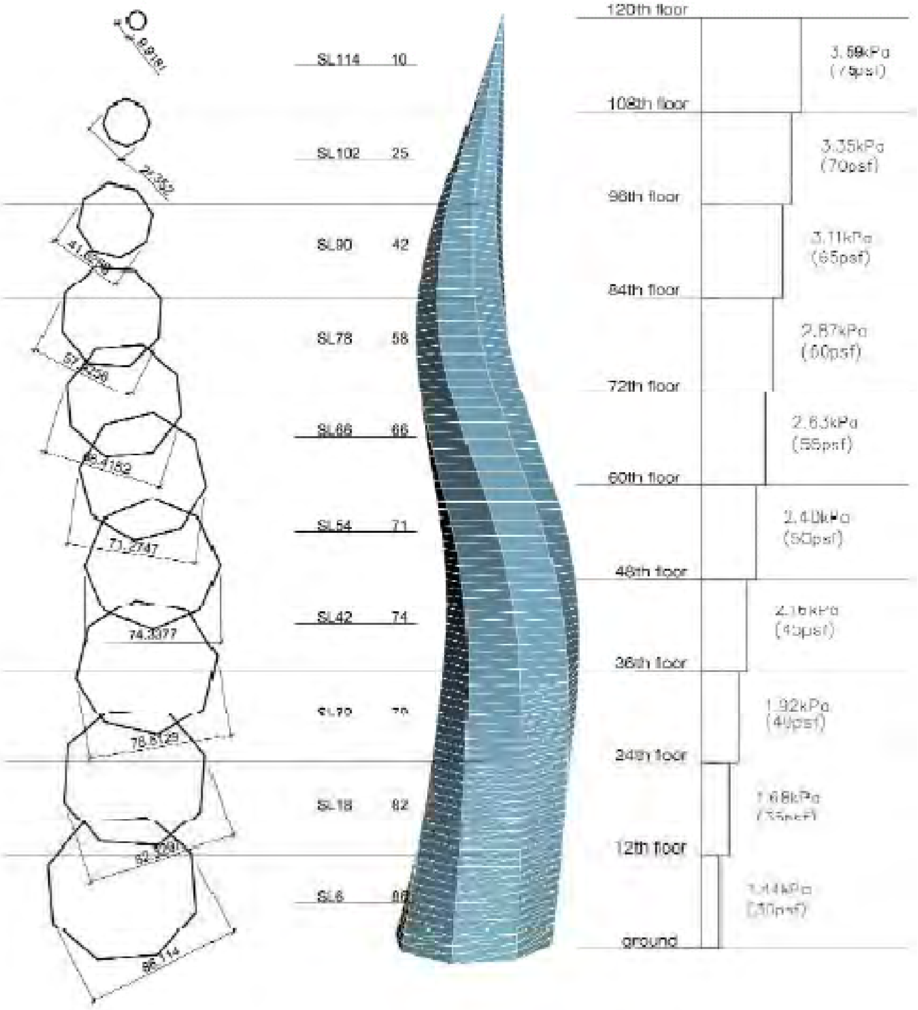

Figure (4-25) Static Wind Loading Diagram.
(Elnimeiri, 2008)

3- Dynamic Openings :

The facade of the Arab world institute-Paris, that is shown in Fig. (4-26), consists of thousands of light-sensitive shutters that control the lightness of the building's interior (1).

Figure (4-26) The Façade of the Arab World Institute-Paris.
Left: From Outside. (Photo by Peter Visontay)
Right: The Panthéon Seen from inside (www.earth-photography.com/Countries/France/Paris_subgallery/France_Paris_MondeArabe.html)

The facade is covered with 113 light sensitive glass sheets, with 16000 movable parts, that work like the human eye when it switches open or closed to control the amount of penetrated light (2). Fig (4-27).

Figure (4-27) The Human eye-Like Openings in Arab World Institute.
(www.skyscrapercity.com/showthread.php?t=349394)

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(1) www.earth-photography.com/Countries/France/Paris_subgallery/France_Paris_MondeArabe.html
(2) Serageldin, I., "Innovation and Authenticity in the Architecture of Muslim Societies: A Study of the Experience of the Aga Khan Award for Architecture".

4- Movable shading device:

Like the one on top of the roof of Misiniaga tower in Malizia, designed by Ken Yeang. Fig.(4-28).

Figure (4-28) Movable Shading on Top of Misiniaga Tower in Malizia.
(www.architecture.uwaterloo.ca/faculty_projects/terri/366_research/Mesiniaga _essay.pdf)

The sun screen structure is made of steel and holds aluminum panels and serves to shade the pool as well as the roof of the buildings [1] as shown in Fig.(4-29).

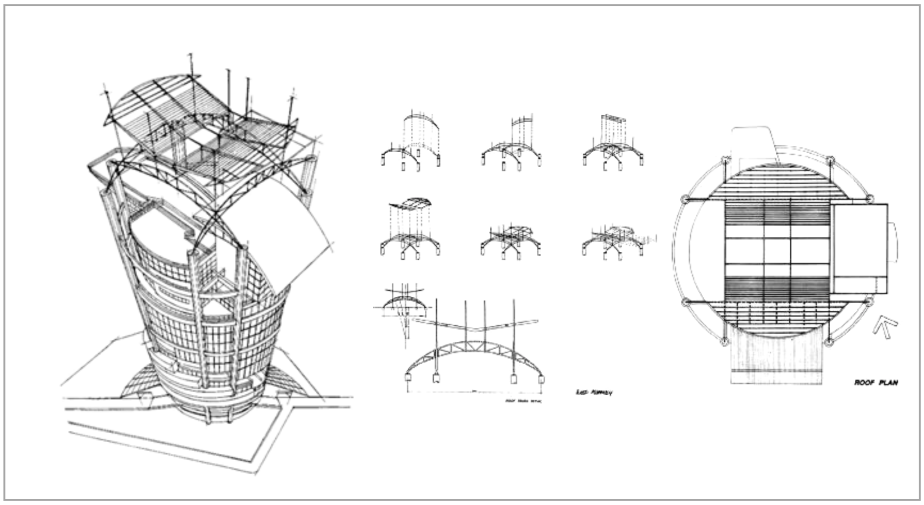

Figure (4-29) Detailed Drawing of the Movable Shading of Misiniaga Tower in Malizia.
(www.yangsquare.com/menara-mesiniaga-in-detail)

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(1) www.yangsquare.com/menara-mesiniaga-in-detail/

IP 16 Partial and excessive action

Principle Explanation:

- *If 100% of a solution is hard to achieve, then, by using 'slightly less' or 'slightly more' of the same method, the problem may be considerably easier to solve.*

Principle Interpretation:

1- Excessive protection "Dobled layer skin":

In our trial to protect the building envelope from being over heated, the first thing that notifies in mind is to use some sort of shading like sun breakers.

The excessive action here is to tie up the whole envelope in another one. This solution does not only provide shading to the openings but also achieve a list of benefits. By choosing proper place for openings, the doubled envelope can create air movemnt that can reduce the temperature of the inner layer.

In winter, by closing the openings, the sun rays penetrate through glass of the external layer, and the heat is trapped inside.

Fig. (4-30) illustrates a section of a simple village house in an isolated island of Ullungdo, in Korea (1).

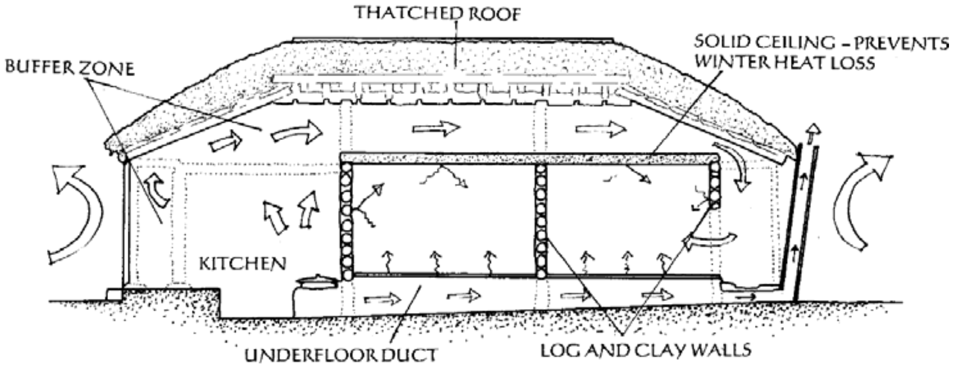

Figure (4-30) Simple Village House in Koria
(Roaf, S., et al., 2001)

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(1) Roaf, S., et al., "Ecohouse: A Design Guide".

It has a double outer-wall construction with the removable outer buffer zone wall, added to provide protection against the driving winds of the island. The two central winter rooms are made of log and clay with high thermal performance and good humidity control. The thick thatched roof provides protection against the winter snow and summer sun.

In this case, the kitchen flue is funneled under the winter living room used both for cooking and heating. As a result, the internal room temperature was comfortable 15.6°C, while it reaches 1.2°C outside. The relative humidity (RH) inside was 44.9 per cent against the external RH of 71.2 per cent (1).

This model house is one of the world's vernacular architectural models. It is called "Hanok" and shown in Fig. (4-31).

Figure (4-31) Hanok: The Korean Traditional House.
(www.asiaenglish.visitkorea.or.kr/ena/CU/CU_EN_10_5_4_1.jsp)

<u>2-Excessive Protection by building partially or completely underground</u>

The south side of Fisher Pavilion in Seattle is buried underground, while the north façade is glazed, opening view to the International Fountain and Green from the nearby Children's Theater (2). The building is illustrated in Figs. (4-32) to (4-34).

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(1) Roaf, S., et al., "Ecohouse: A Design Guide".

(2) The Miller Hull Partnership Official Website.
(www.millerhull.com/htm/nonresidential/SeattleCenter.htm)
The project won five architectural awards between 2001 and 2003.

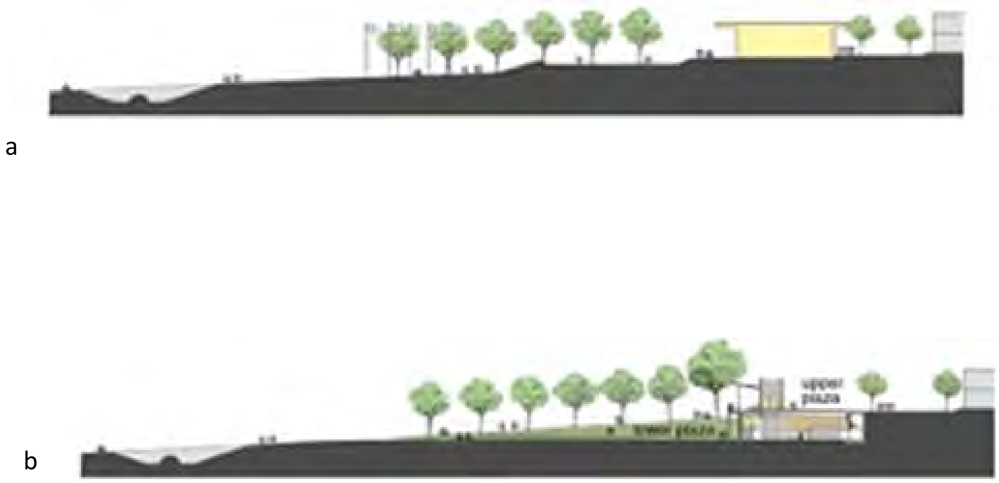

Figure (4-32) Comparison between (a) Original and (b) New Site Section of Seattle Center Fisher Pavilion, Washington.
(www.subsurfacebuildings.com/DiggingfortheGreen.html)

Figure (4-33) The Northern Glazed Façade of Seattle Center-Fisher Pavilion.
(www.millerhull.com/htm/nonresidential/SeattleCenter.htm)

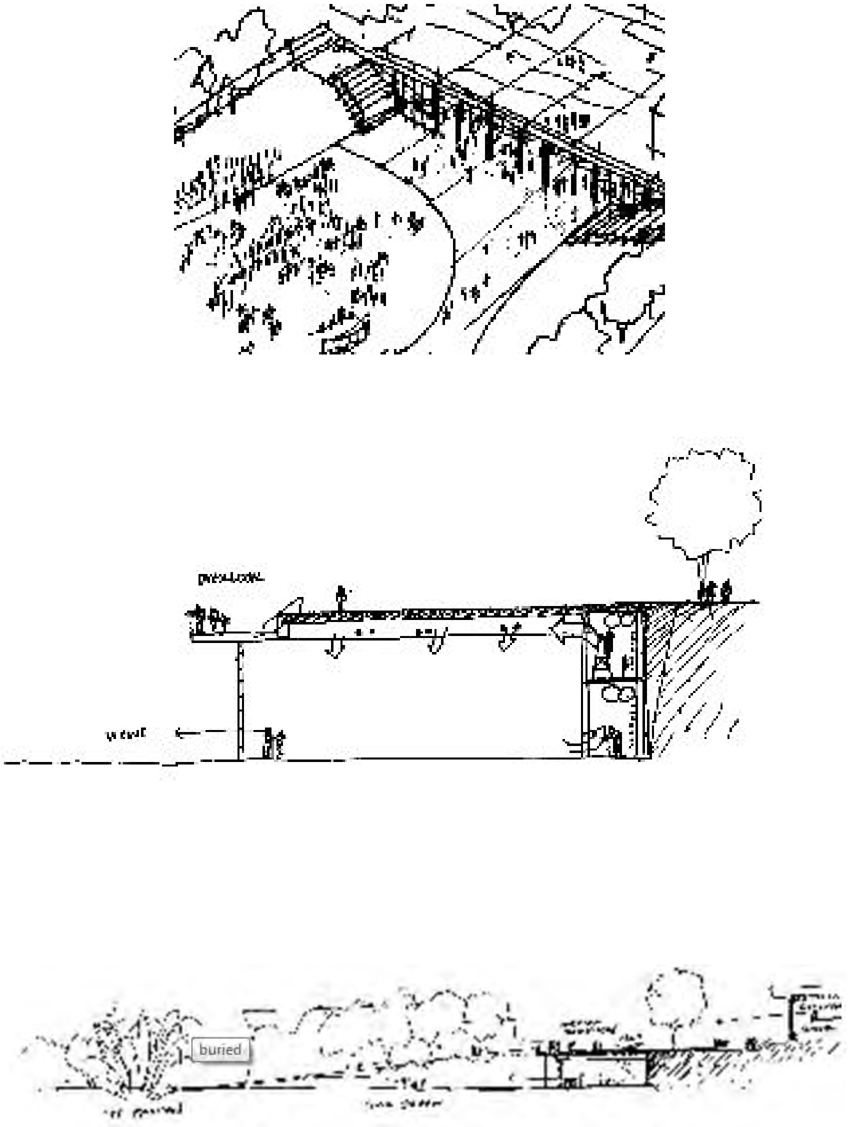

Figure (4-34) Seattle Center-Fisher Pavilion.
Up: Sketch of the aerial view.
Middle: The Two story service corridors.
Down: Section Sketch.
(wsm.wsu.edu/stories/2003/May/concepts.html)

A two-story service corridor allows for accessing and changing the mechanical, electrical, lighting, and sound systems easily and behind the scenes, as shown in Fig. (4-34).

3-Excessive solar exposure: the use of bow window to maximize solar gain in south facades.

The bow window is a window that sticks out from the outside wall of a house (1).

Fig. (4-35) shows a low energy timber house (2). With the openings placed on the south facade. In this context, the bow window could be used to maximize solar gain from morning and afternoon sun.

Figure (4-35) Bow Window Maximizes Heat Gain in a Low Energy House Façade.
(Anderson and Wells, 1981)

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(1) www.answers.com/topic/bow-window

(2) Anderson, B., and Wells, M., “Passive Solar Energy: The Homeowner's Guide to Natural Heating and Cooling”.

IP 25 Self Service:

Principle explanation:

- *Make an object serve or organize itself by performing auxiliary helpful functions*
- *Use waste resources, energy, or substances.*

Principle Interpretation:

1-Using building facades and roofs to place solar collectors.

In the largest solar building in China, the design has been set to host a large number of solar collectors as shown in Fig (4-36).

Figure (4-36) Multi-use Building in China
(www.Echofriend.org)

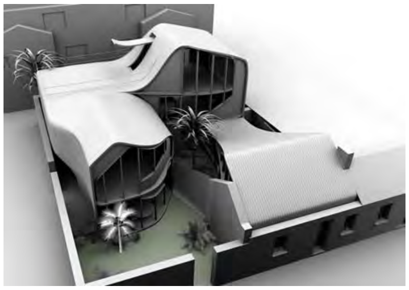

Figure (4-37) Cluster Houses in Sydney
(www.igreenspot.com/cluster-housing-by-enter-architecture)

2-Using building contours to channel wind.

Fig (4-37) illustrates the wind channeling roofs of cluster houses in Sydney, it was designed by Enter Architecture.

Air can flow freely through, longitudinally and laterally. The front part of the layout has the ability to accommodate full sun protection, and an air layer that works on all external surfaces to expel radiant heat from the surfaces directly exposed to sunlight.

The building has a super lightweight transportable material like the curved metal profiles and formed plywood panels (1). Fig. (4-38) illustrates the proposal of the prototype.

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(1) www.igreenspot.com/cluster-housing-by-enter-architecture.

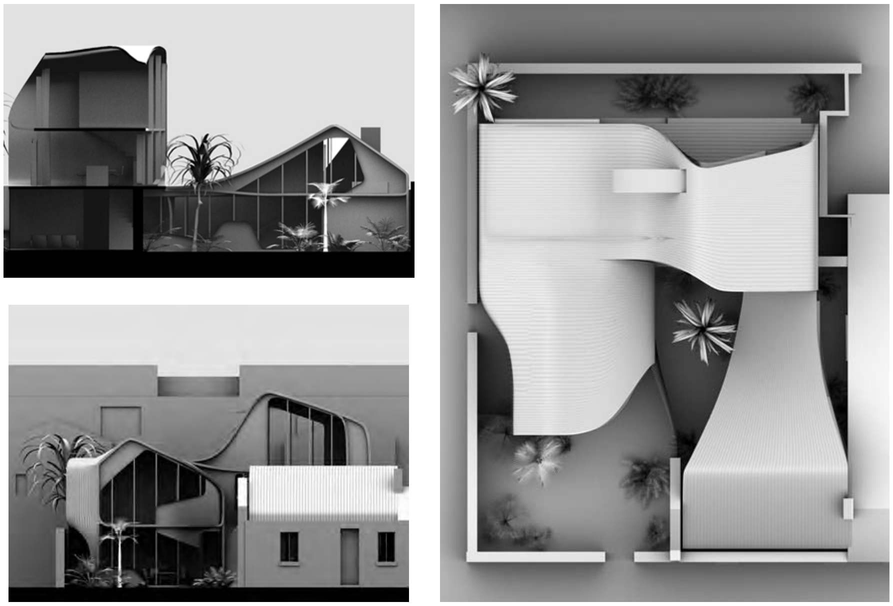

Figure (4-38) Elevations and Aerial View of a Prototype of Cluster House in Sydney.
(www.igreenspot.com/cluster-housing-by-enter-architecture)

3-Using Thermal storage water wall or thermal storage mass wall instead of ordinary walls.

- Thermal storage mass wall:

Fig. (4-39) illustrates thermal mass wall. At day time, vents are open, wall stores heat. At nighttime, vents are closed, and wall heats the room.

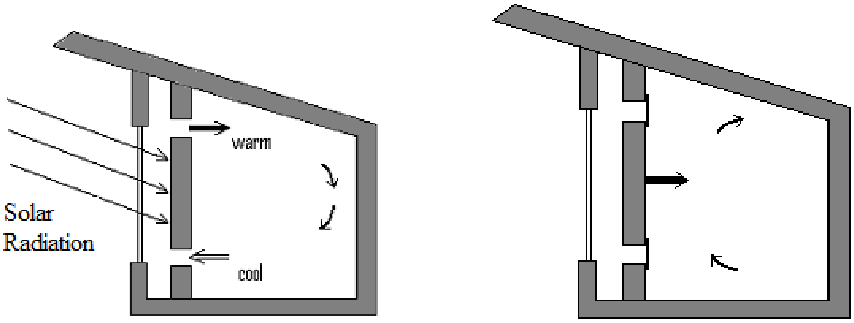

Figure (4-39) Thermal Storage (Trombe) Wall, Daytime and Nighttime Configurations.
(www.pdhengineer.com/courses/r/R-3003.pdf)

- Thermal storage water wall:

Fig. (4-40) shows a small office in New Mexico, where floor to ceiling tubes are filled with water and placed in a row behind south-facing windows to provide heat storage (1).

Figure (4-40)
Thermal Water Wall in Small Office in New Mexico.
(Anderson and Wells, 1981)

Figure (4-41)
A House in Atascadero, California with Water Solar Roof.
(Anderson and Wells, 1981)

The same idea could be applied to the roof, as in a small house at Atascadero, California (2), shown in Fig. (4-41).

Water filled, black, polyvinyl bags covering the roof absorb and store sufficient solar energy to meet 100% of the heating needs of this house. Rigid foam insulating panels slide over the roof at night.

In summer, the panels cover the roof ponds during the day and are opened at night to allow the ponds to radiate heat to the cool sky providing 100% of the required cooling (3).

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(1) Anderson, B., and Wells, M., “Passive Solar Energy: The Homeowner's Guide to Natural Heating and Cooling”.
(2) House designed by Kenneth L. Haggard and John Edmisten.
(3) Anderson, B., and Wells, M., “ibid”.

<u>4-Using Glass as Shading Devices:</u>

Thermo chromic (1) windows are designed to block solar gain. Thermo chromic glazing, shown in Fig. (4-42), mainly consists of liquid or gel polymers sandwiched between layers of glazing.

With cooler temperatures, the light pass freely through the film, when the film warms, the molecules in the film curl up, join together and reflect the light back (2).

Figure (4-42) The Effect of Thermo Chromic Windows
www.thermochromic-polymers.com/thermotropic/index.html

4.3.2. Third Conflict:

4.3.2.1. Turning from TRIZ to BioTRIZ Features

The step will be achieved by looking up table (4-4) that views the relation between TRIZ and BioTRIZ features. The shading parts illustrate the BioTRIZ features equivalent to the contradicting TRIZ features in our conflict.

The result will be that our BioTRIZ conflict is:

Energy versus Energy.

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(1) Another similar kind of glasses is photochromic glasses. Those are suitable for glare control, but not so much for solar heat gain, as they tend to reduce only the visible portion of the spectrum. For example, a photochromic window may darken on a cold sunny day when more solar heat gain is desirable.

(2) Elkadi, H., “Cultures of Glass Architecture”.

Table (4-4):
Distribution of Altshuller's Conflict Features to the BioTRIZ Categories (1)
Looking up "Temperature versus Loss of Energy" conflict:

Operational Field and its Meaning	Contradicting Parameters or Features	Operational Field and its Meaning	Contradicting Parameters or Features
1- Substance Add, remove or change properties of a material.	▪ Weight of moving and stationary object (1,2) ▪ Loss of substance (23) ▪ Quantity of substance (26)	**4- Time** Change speed of process or order of actions	▪ Speed (9) ▪ Duration of action of moving and stationary object (15, 16) ▪ Loss of time (25) ▪ Productivity (39)
2- Structure Add, remove or Regroup structural parts	▪ Stability of the object's composition (13) ▪ Manufacturing precision(29) ▪ Ease of manufacture (32) ▪ Device complexity (36)	**5- Energy** Change energy source or field	▪ Total force (10) ▪ Stress or pressure (11) ▪ Strength (14) ▪ **Temperature (17)** ▪ Illumination intensity (18) ▪ Use of energy by moving and stationary object (19, 20) ▪ Power (21) ▪ **Loss of energy (22)**
3- Space Change position or shape of system or parts	▪ Length of moving and stationary object (3, 4) ▪ Area of moving and stationary object (5, 6) ▪ Volume of moving and stationary object (7, 8) ▪ Shape (12)	**6- Information** Change interactions or regulation of a system or its elements	▪ Loss of information (24) ▪ Reliability (27) ▪ Measurement accuracy (28) ▪ Object-affected and object-generated harmful factors (30, 31) ▪ Ease of operation and repair (33, 34) ▪ Adaptability or versatility (35) ▪ Difficulty of detecting and measuring (37, 38)

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(1) Formed according to: Vincent, J., et al., "Biomimetics: Its Practice and Theory", appendix 2, P. 11.

4.3.2.2. Finding the Inventive Principles:

The following step will be looking up the BioTRIZ matrix to extract the recommended inventive principles.

Table (4-5): BioTRIZ Matrix [(1)]
Looking up Energy versus Energy Conflict:

	Substance	Structure	Space	Time	Energy	Information
Substance	13-15-17 20-31-40	1-3-15 24-26	1-5 13-15 3	15 19 27 29 30	3-6-9 25-31 35	3-25-26
Structure	1-10-15 19	1-15-19 24-34	10	1-2 4	1-2-4	1-3-4-15-19 24 25-35
Space	3-14-15 25	2-5-10 15-19	4-5 36-14 17	1-19 29	1-3-4 15-19	3-15-21-24
Time	1-3-15 20 25-38	1-4-6 15-17-19	1-4-7 38	2-3 11 20 26	3-9-15 20-22 25	1-3-10 19 23
Energy	1-3-13 14-17-25 31	1-3-5 6-25-35 36-40	1-3-4 15-25	3-10 23 25 35	**3-5-9** **22-25** **32-37**	1-3-4 15-16 25

The shaded parts illustrate the features of our conflict and the resulted inventive principles.

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(1) Copied from: Vincent, J., et al., "Biomimetics: Its Practice and Theory", p. 477.

By looking the BioTRIZ matrix in table (4-5), we will find that the recommended inventive principles for the conflict “Energy versus Energy” will be:

IP 3 Local Quality.

IP 25 Self Service.

IP 22 Blessing in Disguise.

IP 5 Merging.

IP 9 Preliminary Anti Action.

IP 32 Color Change.

IP 37 Thermal Expansion.

The first three principles were previously reviewed in the first conflict. **Their repeated appearance in both conflicts focuses on their important role in framing the solution.**

The principle analysis will be continued, starting from IP 5 Merging.

4.3.2.3. Principles Interpretation:

IP 5 Merging:

Principle Explanation:

- *Bring closer together (or merge) identical or similar objects or operations in space*

Principle Interpretation:

1- Multi component skin facades

The principle again, suggests the multi layered skin, where the similar operations are brought together in space. Those operations are:

Protecting the building (Isolation-Shading), and feeding it (ventilation-lighting) (1).

Double or triple glazing with shading blinds inside may also exemplify the concept.

An Example is 88 Wood Street in London, designed by Richard Rogers. The building hosts three linked blocks of office accommodation. Fig (4-43)

The triple-glazed façade is formed of single panels of highly transparent glass. The inner faces of the external panes have a low emissivity coating which further reduces solar gain, while the cavity between the double glazed units and the third panel which is 14 cm wide, is fitted with motorized, integral horizontal blinds with perforated slats. Photocells on the roof monitor light conditions and adjust the angle of the blinds. (2)

Air from the offices is drawn into the main perimeter extract ducts within the cavity via ducts within a suspended ceiling and then expelled at roof level. When the blinds are closed they act as a heat sink whilst the perforations admit a measure of natural light.

The result is that there are substantial savings in the energy normally needed to cool such spaces and a high rate of air change in the building at double the average for a typical office block.(3)

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(1) The same interpretation of IP 3 Local Quality, viewed at p. 180.

(2) ww.richardrogers.co.uk/Asp/uploadedFiles/Image/1376_88woodst/RSHP_A_JS_1376_L_E_GB.PDF.

(3) Smith, P., “Architecture in a Climate of Change”.

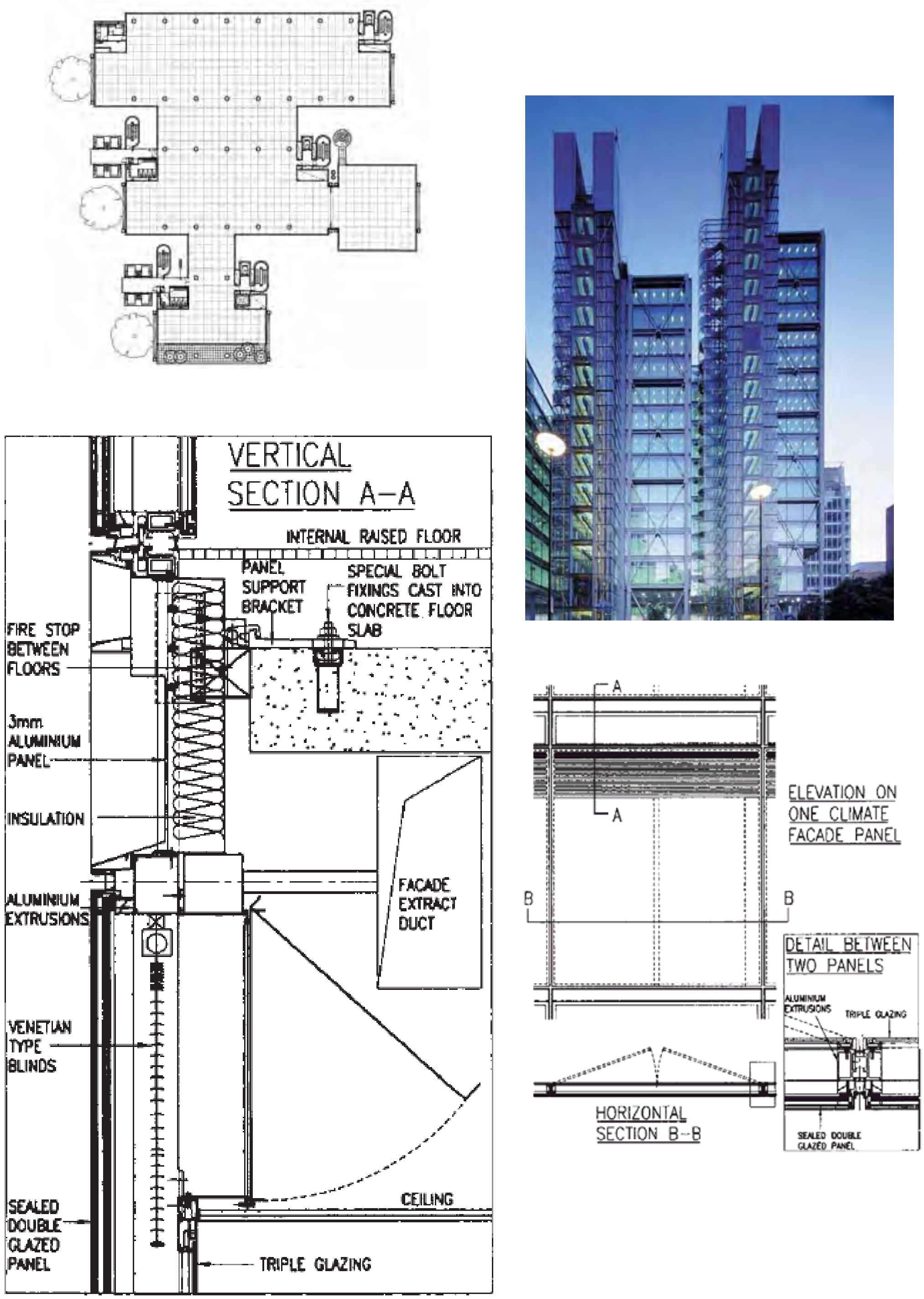

Figure (4-43) 88 Wood Street.
Up: Plan and View of the building. Down: Sections, Elevation and Detail of the facade.
(Smith, 2005)

The second example was suggested by a final year architecture students in Queens University. He has proposed that merging louver system within double skin façade glazing achieves the function and yet protects the louver system from damage (1).

The contradiction which this solution unfolds was not mentioned, it seems as if the solution was more concerned with protecting the louver system itself. However the solution still offers protection to both, the space and the envelope.

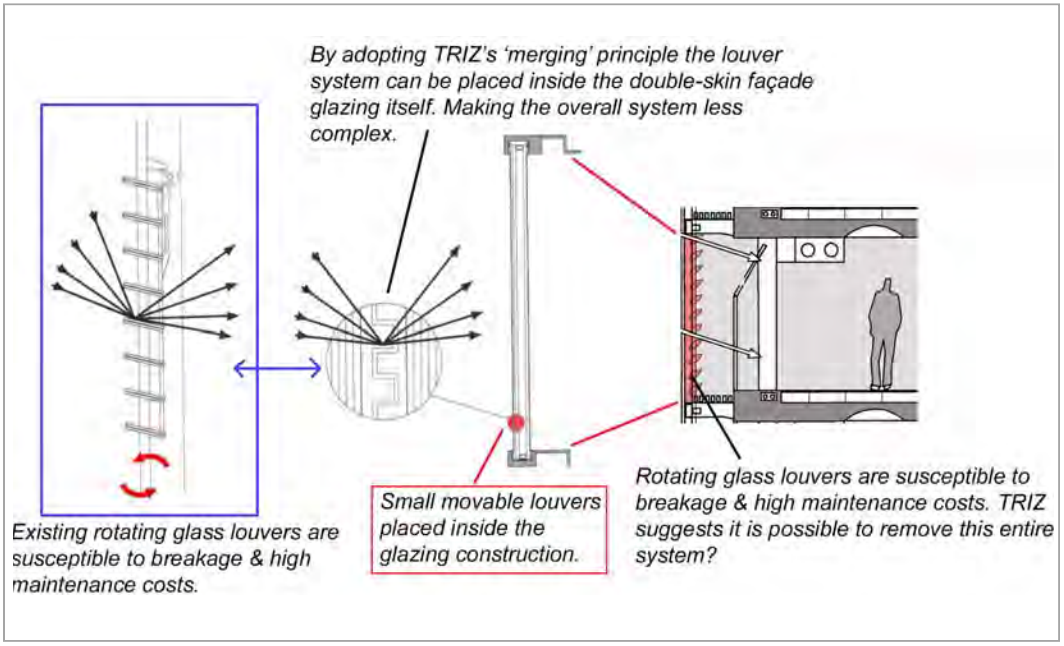

Figure (4-44) Placing Movable Louvers inside the Glazing Construction as an Application for IP (5) Merging
(Mann and Catháin, 2005)

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(1) Mann, D., and Catháin, C., " Using TRIZ in Architecture: First steps".

IP 9 Preliminary Anti Action

Principle Explanation:

- *If it will be necessary to perform an action with both harmful and useful effects, this action should be replaced with anti-actions to control harmful effects.*
- *Create beforehand actions in an object that will oppose known undesirable working stresses later on.*

Principle interpretation:

1- Eliminating ceiling by using pyramid form, and eliminating walls by using sloped walls

The harmful action here is that *"the ceiling and walls are being heated"*. In case if we eliminate the ceiling, the harmful action or *"the overheating"* will no longer take place.

Eliminating the ceiling can take place by using pyramid form where the area of the roof is zero, or by adopting other forms like the egg of Norman's Foster in City Hall, London, shown in Fig. (4-45).

The beforehand action here is hiding the sun facing façade by stepping inwards, and in the same time the roof area was minimized.

Figure (4-45) Eliminated Ceiling and Walls in City Hall Building, London.
(http://designcliff.wordpress.com/2008/08/)

2- **Eliminating the envelope exposed area by building underground.**(1)

3- **Eliminating the envelope affected area by planting the roof.**

Fig. (4-46) shows the school of Art in Singapore where the whole ceiling is planted.

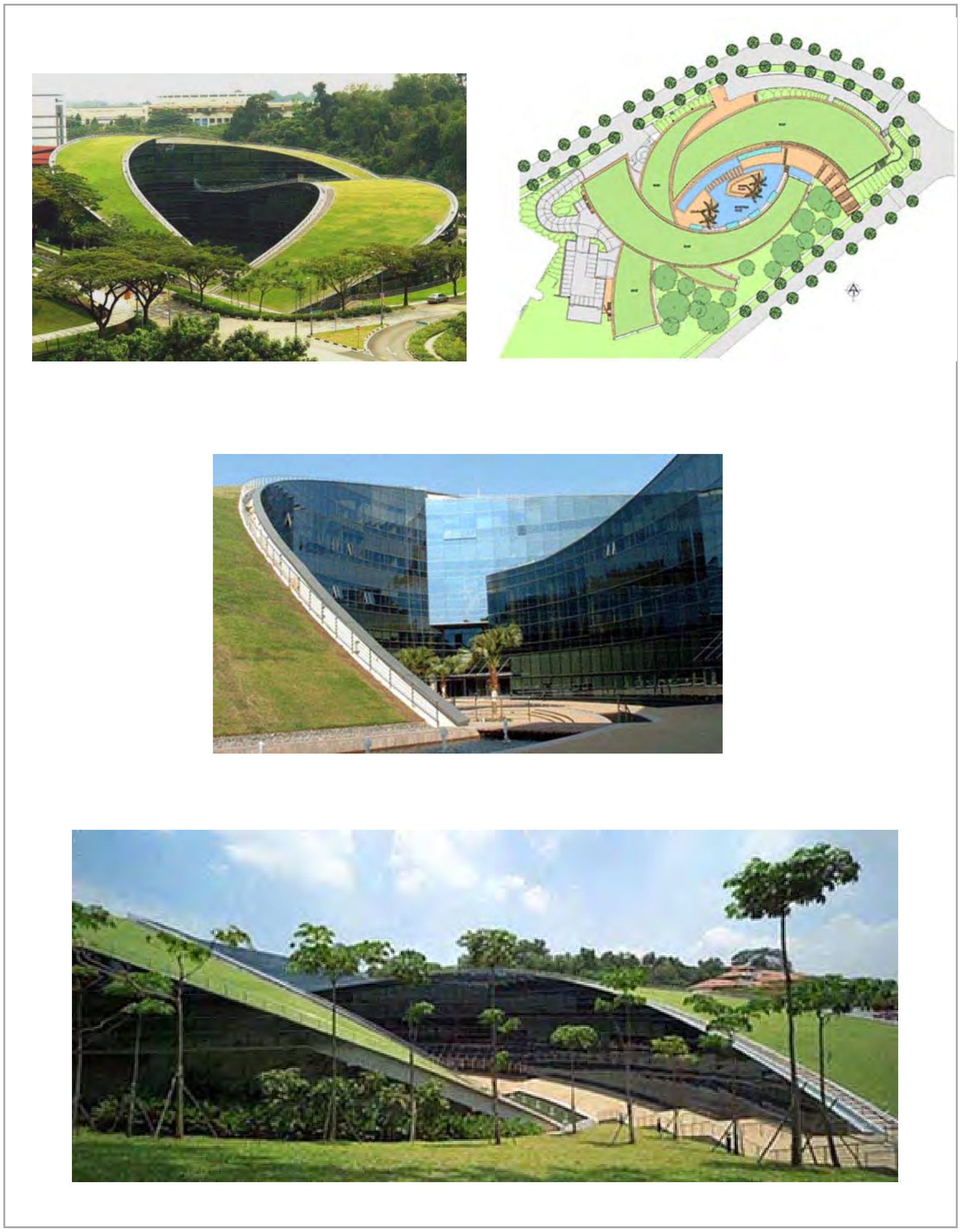

Fig. (4-46) School of Art, Singapore

(www.nikiomahe.com/architecture-design/amazing-green-roof-art-school-in-singapore)

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(1) The same interpretation of IP 16 “Partial and Excessive Action”: “Excessive protection by building partially or completely underground”, viewed at p. 191.

IP 32 Color change:

Principle Explanation:

- *Change the color of an object or its external environment.*
- *Change the transparency of an object or its external environment.*
- *Change the emissivity properties of an object subject to radiant heating.*

Principle Interpretation (1):

1- Changing façade colors to control Heat Gain

The national aquatic center or the Water Cube, one of the Beijing 2008 Olympic buildings has a unique structure cladding, that consists of translucent ETFE (Ethyl tetra fluoro ethylene) (2), a tough, recyclable material that weighs just one percent of an equivalent sized glass panel.

The Water Cube displays a different color pattern each evening. The patterns are computer-controlled (3).

The applied technology in water cube building, shown in Fig. (4-47) could be used to regulate the heat gain in the building envelope. If it could be managed to change the facade colors, then the heat gain can be increased in winter by using dark colors and decreased in summer by using light colors in the same façade.

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(1) The interpretations: (2), (3) and (4) are copied from the 40 Inventive (Architecture) Principles with Examples for Mann and Catháin at (www.triz-journal.com/archives/2001/07/b/index.htm).

(2) www.e-architect.co.uk/beijing/watercube_beijing.htm

(3) www.cree.com/press/Olympics.asp
Since this work is concerned with Bio-inspired architecture, it should be mentioned that this building was inspired by soap bubbles.

Figure (4-47) The Changing Colors of Water Cube at Night.
(*http://en.beijing2008.cn/cptvenues/venues/nac/headlines/n214288141.shtml***)**

Figure (4-48) Inside the Water Cube
(www.blog.rehava.com/beijing-olympics-water-cube)

Figure (4-49) The Water Cube Ceiling from Inside
(www.cree.com/press/Olympics.asp)

2- **The use of thermo chromic glasses (1)**

3- **The use of deciduous trees, that give shade in summer but let sunlight pass through in winter:**

Fig. (4-50) illustrates the concept.

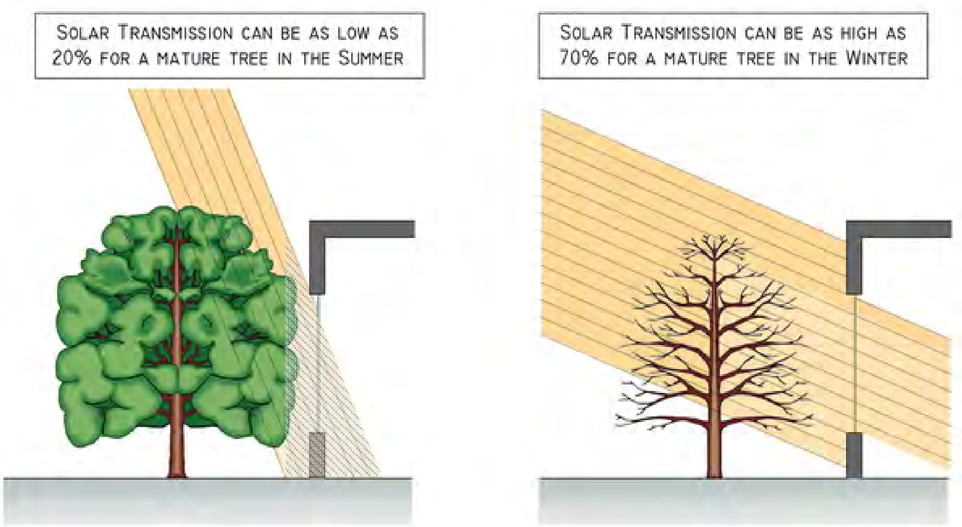

Figure (4-50) Deciduous Tree
(www.architecture.uwaterloo.ca/faculty_projects/terri/carbon-aia/strategies1b.html)

4- **Low emissivity glass:**

It is used in the Regional Center for the Arts (RCA), a high school in Trumbull, Connecticut, shown in Fig. (4-51).

The crescent-shaped, north-facing entry elevation is almost entirely finished in low-emissivity glass, which welcomes daylight but mitigates heat gain (2).

5- **Use of light and dark colored panels to assist thermal management**

The same interpretation recommended by IP Segmentation of color (3).

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(1) Previously viewed in the first conflict, p. 198.
(2) www.archrecord.construction.com/schools/08_Regional_Center_Arts.asp
(3) Previously viewed at p. 179.

Figure (4-51) Low Emissivity Glass in the Regional Center for the Arts.
Left: The Corridor Sprawls from One End of the Building to the Other.
Right: Northern Façade.
Down: Site Plan.
Photo by Robert Benson.
(www.archrecord.construction.com/schools/08_Regional_Center_Arts.asp)

<u>IP 37 Thermal Expansions:</u>

The interpretation of this principle was previously viewed in TRIZ matrix step (1).

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(1) At p. 166.

Summary:

Chapter Four aimed at practicing TRIZ and BioTRIZ methods to find a solution to a proposed green architectural design problem.

The proposed problem was “How can we regulate the heat gain through the building envelope?”, and the contradictions formed were:”Temperature versus loss of Energy”, and “Stress versus Object affected harmful”.

A set of inventive principles resulted as recommendations of TRIZ and BioTRIZ matrix, and those principles were hence interpreted into a set of architectural solutions and treatments. Those treatments were viewed with examples from the world green architecture that best describe the resulted solutions.

For example, IP 1 Segmentation was interpreted into segmentation of surface to produce shadow and segmentation of skin layers to produce air movement in between, in order to cool the inner envelope layer.

Table (4-6) views all the inventive principles recommended by both TRIZ and BioTRIZ for the proposed problem, and their architectural interpretations.

Some observation was taken out of table (4-6):

- Despite the fact that all the inventive principles in the table help in figuring the solution, the repeated inventive principles still have a priority. The priority degrees are seen as follows:
    - Principles highlighted in *blue* have the third priority; as they were recommended by the same matrix; the BioTRIZ, to solve the same defined conflict;” Energy versus Information”.
    - Principles highlighted in *red* have the second priority as they were recommended by the same matrix, to solve two different defined conflicts.
    - Principles highlighted in *orange* have the first priority as they were recommended by both matrices, to solve two different defined conflicts.

Table (4-6): Inventive Principles Suggested by TRIZ and BioTRIZ Matrices to solve the proposed Problem "Heat Gain Regulation through the Building Envelope".

		TRIZ	BioTRIZ
First Conflict	**The conflict**	Stress versus Object generated Harmful	Energy versus Information
	Inventive Principles that are Recommended to unfold the Conflict	IP 22 Blessing in Disguise IP 2 Take Out IP 37 Thermal Expansion	IP 1 Segmentation IP 3 Local quality IP 4 Asymmetry IP 15 Dynamics IP 16 Partial or excessive actions IP 25 Self service.
Second Conflict	**The conflict**	Stress versus Object affected Harmful	Energy versus Information
	Inventive Principles that are Recommended to unfold the Conflict	IP 2 Take Out IP 33 Homogeneity IP 27 Cheap Disposable IP 18 Mechanical Vibration	IP 1 Segmentation IP 3 Local quality IP 4 Asymmetry IP 15 Dynamics IP 16 Partial or excessive actions IP 25 Self service.
Third Conflict	**The conflict**	Temperature versus Loss of Energy	Energy versus Energy
	Inventive Principles that are Recommended to unfold the Conflict	IP 17 Another Dimension IP 21 Skipping IP 35 Parameter changes IP 38 Strong oxidants	IP 3 Local Quality. IP 25 Self Service. IP 22 Blessing in Disguise. IP 5 Merging. IP 9 Preliminary Anti Action. IP 32 Color Change. IP 37 Thermal Expansion.

Table (4-7): Major Recommendations by TRIZ and BioTRIZ to the Proposed Problem, “Heat Gain Regulation through the Building Envelope”

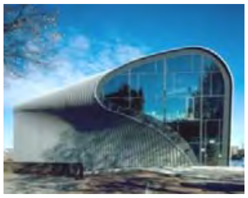
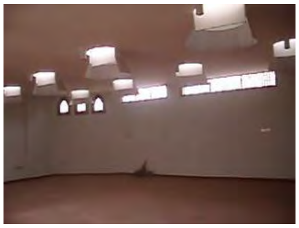
IP 1 Segmentation	Segmentation of **Surface** to provide shading.	 
	Integrated and Differential Segmentation of **Shape** to provide shading.	 
	Segmentation of **Layers**: Perpendicular to the façade to provide shading.	
	Segmentation of Layers: parallel to the façade to produce ventilation cavity.	
IP 2 Take Out	Let light pass but not heat	
	Let light pass but not air	

Table (4-7) continued:

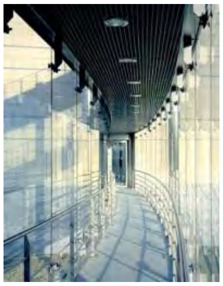
IP 3 Local Quality	Multi component skin facades for multifunction fulfillment. (Ventilation- Isolation- Shading- Lighting). **(Lately recommended by IP 5 Merge)**	
	Non uniform surface to provide shading **(Previously recommended by IP 1 Segmentation)**	
IP 4 Asymmetry	Asymmetry in form to provide shading.	
	Asymmetry in sun breakers orientation to provide better shading.	
	Asymmetry to serve aerodynamically.	

Table (4-7) continued:

IP 5 Merging	Multi layered Skin Double/triple glazing.	
IP 9 Preliminary anti-action	Eliminating ceiling by using pyramid or similar forms, and eliminating walls by using sloped walls.	
	Eliminating the envelope exposed area by building underground. **(Previously recommended by IP 16 Partial and excessive action**	
	Eliminating the envelope affected area by planting the roof.	

Table (4-7) continued:

IP 15 Dynamics	Environmentally conscious Rotating spaces.	
	Allow for air movement **(Previously recommended by IP 4 Asymmetry)**	
	Dynamic openings.	
	Movable shading devices.	

Table (4-7) continued:

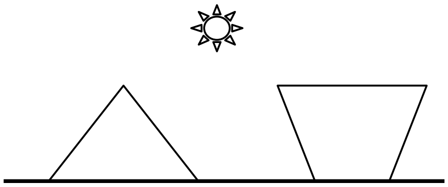
IP 16 Partial and excessive action	Excessive protection by dobled layer skin.	
	Excessive protection by building partially or completely underground.	
	Excessive solar exposure by the use of bow window to maximize solar gain in south facades.	
IP 17 Another Dimention	Tilt walls and roofs to protect them from the sun	
	Vertically Assembled building blocks offers protection from the sun and harsh climate	

Table (4-7) continued:

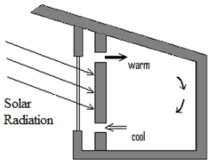
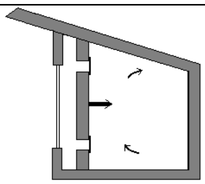
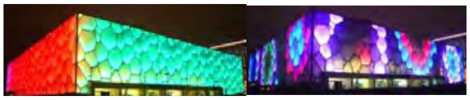
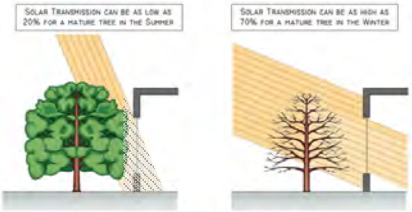
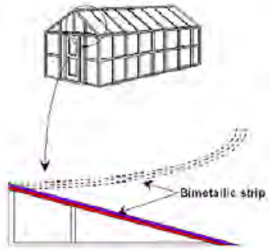
IP 22 Blessing in disguise	Using heat to generate power.	
IP 25 Self Service	Using building facades and roofs to place solar collectors.	
	Using building contours to channel wind.	
	Using thermal storage water wall and roof or thermal storage mass wall instead of ordinary walls and roofs.	   
	Using glass as a shading device.	 

Table (4-7) continued:

IP 32 Color change	Changing façade colors to control heat gain.	
	The use of thermo chromic glass. **(Previously recommended by IP 25 Self Service)**	
	The use of deciduous trees, that give shade in summer but let sunlight pass through in winter.	
	Low emissivity glass.	
IP 33 Homogeneity	Building with the same material of the environment	
IP 37 Thermal Expansion:	Bi-metallic hinges offer self-opening windows/ventilators.	

Conclusions:

The use of TRIZ and BioTRIZ methods for the proposed problem: "Regulating heat gain through the building envelope" has resulted in a set of recommendations that are viewed in table (4-8).

Shaded Cells represent applications with repeated recommendations by other principles.

Table (4-8) Inventive Principles Recommended by TRIZ and BioTRIZ to Solve the Proposed problem "Heat Gain Regulation through the building Envelope".

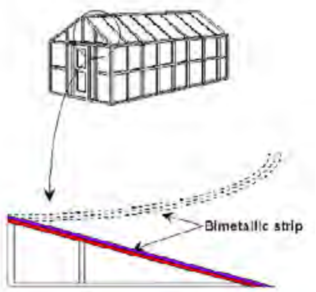
IP 22 Blessing in disguise
 Use heat to generate power.
IP 37 Thermal Expansion
 Bi-metallic hinges offer self-opening windows/ventilators.

Table (4-8) Continued:

<table>
<tr><th colspan="4">IP 3 Local Quality</th></tr>
<tr><td colspan="2">
Multi component skin facades
also recommended by IP 5 Merging
and IP 1 Segmentation</td><td colspan="2">
Shading Non uniform surface
also recommended by
IP 1 Segmentation</td></tr>
<tr><th colspan="4">IP 25 Self Service</th></tr>
<tr><td>
Envelope hosts solar collectors</td><td>
building contours channel wind</td><td>
Thermal storage water roofs and walls</td><td>
Thermo Chromic Glass.
Also recommended by IP 32
Color Change</td></tr>
</table>

Table (4-8) Continued:

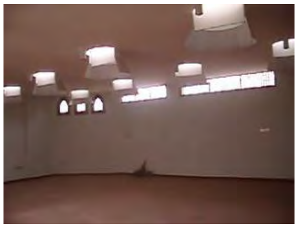
<table>
<tr><th colspan="6">IP 2 Take Out</th></tr>
<tr><td colspan="3">
Let light pass but not air</td><td colspan="3">
Let light pass but not heat</td></tr>
<tr><th colspan="6">IP 1 Segmentation</th></tr>
<tr><td colspan="2">
Segmentation of **Surface** to provide shading.</td><td colspan="2">
Segmentation of **Shape** to provide shading</td><td colspan="2">
Segmentation of **Layers**: *parallel* to the façade to produce ventilation cavity or *perpendicular* to the façade to provide shading.</td></tr>
<tr><th colspan="6">IP 4Asymmetry</th></tr>
<tr><td colspan="2">
Asymmetry to serve aerodynamically.</td><td colspan="2">
Asymmetry in form to provide shading.
Also recommended by IP 9 Preliminary anti action</td><td colspan="2">
Asymmetry in sun breakers orientation to provide better shading.</td></tr>
</table>

Table (4-8) Continued:

IP 15 Dynamics			
 Allow for air movement **Also recommended by IP 4 Asymmetry**	 Environmentally conscious Rotating spaces.	 Dynamic Openings	 Movable shading devices.

IP 16 Partial and excessive action		
 Excessive protection by dobled layer skin.	 “Building Underground” **Also recommended by IP 9 Preliminary anti-action**	 Excessive solar exposure by the use of bow window to maximize solar gain in south facades.

From table (4-8), the following can be concluded:

1- **To help framing the solution, when dealing with the heat gain regulation through the building envelope, it should be focused on:**

- Multi component skin facades that fulfill multi functions like insulation, shading, ventilation and lighting.
- Shading Non uniform surfaces.
- The use of bi-metallic hinges that offer self-opening windows.
- Allowing light to pass into the space without heat.
- Using thermo chromic glass instead of ordinary glass, as it helps shading the interior when the temperature rises outside.

It may be also focused on:

- Aerodynamic strategies that helps evaporative cooling along the facades.
- Building completely or partially underground.

2- **TRIZ and BioTRIZ methods were proved to be dependable ways that the designer can use to figure out his solution.**

3- **Every designer may form different contradictions to the same problem according to his own vision and analysis, and also different interpretation to the same inventive principles. This gives TRIZ and BioTRIZ a distinctive value as rich flexible tools.**

CONCLUSIONS AND RECOMMENDATIONS

The more we function
like the natural world,
the more likely we are to fit in
..Janine Benyus

Conclusions

- Biomimicry is the study of forms, structures and mechanisms of natural living organisms to perform their functions.

- BioTRIZ method is rich flexible way that architects can use to figure out their environmental designs. It is ‘rich’ because the use of BioTRIZ to follow nature unlimited geniality will enrich the design process with valuable advices and ideas, and ‘flexible’ because it can be applied to any kind of problems, and because each designer can come up with different solutions according to his personal problem framing.

- According to the reading of the comparison between biology and technology that was presented by Vincent et al., which concludes that “*technology solves problems largely by manipulating usage of energy, while biology uses information and structure, two factors largely ignored by technology”*, it is concluded that **design in nature guides architecture towards the solutions based on “information”, and “structure”.**

- The thesis has presented interpretations to some of the inventive principles linked to “Information” and “Structure”. For example, “Blessing in disguise”, “Self service”, “Segmentation”, “Taking out”, “Local quality”, “Merging” and “Slightly less-slightly more” were all interpreted from an environmental architecture point of view. But still there are some other principles like “Feed back”, “The other way round”, “Universality”, “Nested Dolls”, “Intermediary”, “Discarding and recovering” and “Composite material” that are not yet interpreted in the field of environmental architecture.

- **“**Natural designs has a set of characteristics, among which:
    - Depending on the sun and other renewable energy sources.
    - Using the only necessary energy and resources.
    - Depending upon Symbiosis.
    - Depending upon total recycling.
    - Tapping the power of limits.
    - Depending upon fractals.
    - Depending upon network creation instead of linearity.
    - Depending upon functional forms.
    - Relying upon swarm intelligence.
    - Developing diversity of possibilities.
    - Adjusting to the Here and Now.
    - Avoiding excesses and “overbuilding”.

- In the field of architecture, there are nine possible levels in which biomimicry can take place, **taking in respect that nature works in systems.** The architect can mimic a natural “concept”, natural “process”, “morphology”, “form”, “structure”, “skin” or “material”. “Expressions” and “symbols” can also be borrowed from nature to complete the architectural experience. **It should be taken into consideration that architecture also works in systems.**

Recommendations

- BioTRIZ and TRIZ matrices should be added to the curriculum of the environmental design, in the under graduate architecture education in Egypt.

  This may be a relatively late step comparing to the fact that TRIZ is being taught, in a simplified form, for 11 years children in Russia.

- Efforts should be made to establish an architectural database of biomimicry. The official site: (www.asknature.com) (1), and the master thesis: "Biotic Balance between the Organisms and the Surrounding Environment as an Approach to Suitable Urban Design-Desert Zone Biome as a Practical Application" (2) may be good models.

- Further studies should be made to focus on the environmental architectural interpretations to the inventive principles of the features, "Structure" and "information", as those two solutions largely used in solving contradictions in nature.

- More attention should be given to the "responsive skin" issue. This is because the hi-technology of the computerized openings will not be a practical feasible solution in our developing country. The naturally responsive skin that is made of bimetallic strip may offer a practical, low price solution that depends only on a precise scientific awareness of the physical properties of materials.

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(1)The website interface is viewed in the appendix, p. 263.

(2) Shebat El Hamed, Ahmed, Faculty of Engineering, Cairo University.

- Further detailed Studies should be handled to produce self coloring wall panels. This may result in establishing a new era in material industry, where self coloring prefabricated sheets and claddings can be produced, depending upon the nanostructure of materials. These claddings would eliminate all the painting and repainting requirements and cons.

- Further studies could be performed to explore the concept of Ecomimicry in architecture. Ecomimicry is another carnation of the Bio-inspired design; it is defined as the practice of designing socially responsive and environmental responsible technologies for a particular locale based upon the characteristics of animals, plants and ecosystems of that locale (1). It is claimed that this trend is more environmentally conscious than Biomimcry. Hence, such studies may be important to find out whether and how Ecomimicry can help the field of environmental architecture.

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(1) Marshall, A., “The Theory and Practice of Ecomimicry”.

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You will find something far greater in the
woods than you will find in books.
Stones and trees will teach you that which
you will never learn from masters.
..St. Bernard

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- www.worldchanging.com
- www.reading.ac.uk
- www.richardrogers.co.uk
- www.rhenotherm.com
- www.sahbaarchitect.com
- www.solarwall.com
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APPENDICES

"Human subtlety will never
devise an invention more beautiful, more simple
or more direct than does nature
because in her inventions nothing is lacking,
and nothing is superfluous."
..Leonardo da Vinci

Appendices

Appendix 1

Case Study for Biomimetics Using TRIZ

Cats Claw Wheel

In many areas, the winter temperatures go below 0 ºC, leading to dangerously icy road conditions. But the spikes or chains often attached to wheels for the whole winter damage ice-free roads. It is inconvenient to be changing continually between special winter and summer tires or putting chains on and off the wheels. It would be better to have an instantly changing tire.

So the problem can be formulated as: “we need adequate friction between a wheel and a road under variable road surface conditions. The friction must also vary without the weight of the vehicle changing.

The big question here would be: “How can we change the gripping mode instantly when the type of surface changes?”

A relevant functional biological prototype would be a cat’s paw with claws that can be withdrawn, allowing the soft pad to contact the ground.
Figs. (a-1) and (a-2) shows the natural model and resulted product using TRIZ and BioTRIZ methods.

The case study was viewed by Vincent et al., (1), and here is an attempt to put the methodology used, in a frame that is easy to use (2).

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(1) Vincent, J., et al. "Biomimetics: its practice and theory", p. 479.
(2) The case study was framed here, and the frame model was viewed at p. 152.

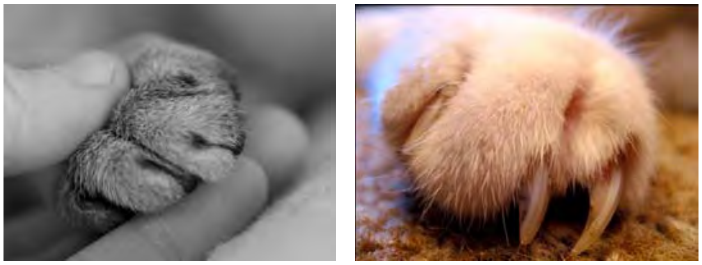

Figure (a-1) The Cat-Paw

(Left) without claws
(http://www.flemploymentlawblog.com/2009/01/articles/age-discrimination-1/court-rejects-cats-paw-theory-vacates-jury-verdict/)
(Right) with claws
(http://www.stockphotosofcats.com/images/070616114860_Cats_Paw_in_a_Human_Hand_LG.jpg)

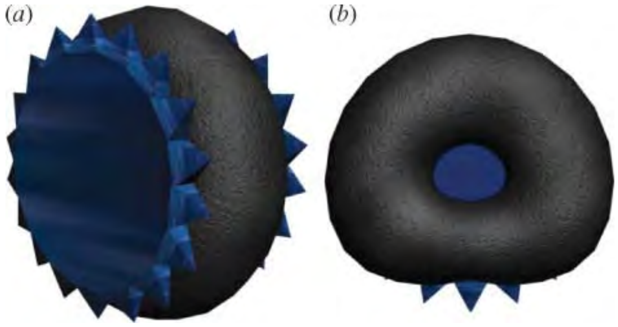

Figure (a-2) The 'Cat-Paw' Wheel,
(a) Inflated and (b) ready for icy surfaces.
(Vincent et al., 2006)

Table: (a-1) Biomimetic Contradiction Solving Form, Applied for the Cat Paw Wheel Case Study *(Formed by researcher out of Vincent et al., 2006)*:

The Problem Definition
(The Basic Question)
“How can we change the gripping mode instantly when the type of surface changes?”

Conflict 1 (Question Form 1)		**Conflict 2** (Question Form 2)		**Conflict 3** (Question Form 3)	
(How to increase the *force* in contact with the road without increasing the *weight* of the vehicle)		(How to minimize contact surface *area* without losing *weight* of the object)		(How to reduce the ground surface area without losing adaptability and composition stability)	
-- Force vs. weigh of moving object		-- Area of moving object vs. weigh of moving object		-- Area of moving object vs. stability of the objects composition And Area of moving object vs. adaptability or versatility	
-- F(10)*F(1)		-- F(5)*F(1)		-- F(5)*F(35) and F(5)*F(13)	
TRIZ	**BioTRIZ**	**TRIZ**	**BioTRIZ**	**TRIZ**	**BioTRIZ**
IP (1) IP (8) IP (18) IP (37)	**IP (1)** IP (3) IP (14) **IP (15)** **IP (17)**	IP (2) IP (4) IP (29) **IP (17)**	IP (3) **IP (15)** **IP (17)**	IP (2) IP (11) IP (13) **IP (15)** IP (30) IP (39)	**IP (1)** **IP (17)** IP (19)

The Common Inventive Principles
IP (1) **IP (15)** **IP (17)**
IP (1) Segmentation: the cat’s paw is segmented into several pads and claws
IP (15) Dynamics: the claws can be deployed or retracted
IP (17) Another dimension: when the claws are deployed the paw moves into the third plane.

The Solution

Soft and sharp modes of operation of the wheel should be switched on and off in time.

Appendix 2
The Inventor, (or discoverer) of TRIZ theory
Genrich Altshuller

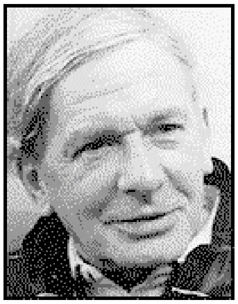

Fig. (a-3)
Genrich Altshuller

Fig. (a-4)
Darell Mann

- From 1946-48, he served in the Russian navy as 'Inspector of Inventing' and was able to explore this conviction by studying the patents lodged by inventors. This was made relatively easy in that all inventions were owned by the state and the inventor was issued with a single page 'Author's Certificate'. Thus, Altshuller, together with another, Raphael Shapiro, were able to go through 200,000 patents and reduce them to 40,000 for their study.
- With a sense of patriotism, they wrote to Stalin explaining how Soviet engineers and scientists could do better. The result was arrest, torture and a sentence of 25 years in Siberia for attempting to undermine the state.
- In 1953, Stalin died and, in 1956, Altshuller published his first article on TRIZ.
- During the period 1974 - 85, he wrote over 14 books and published in education and the media. For children, there was a regular TV show and a book 'And Suddenly an Inventor Appeared'(1)
- Nobody had heard about TRIZ outside Russia until 1985 when two 'followers' migrated to the USA.

- In 2001, Darell Mann, an industrial Fellow, Department of Mechanical Engineering, University of Bath, and Conall Cathain a senior lecturer at School of Architecture, Queen's University, formed architectural examples for the TRIZ 40 Inventive principles (2).

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(1) Spain, E., TRIZ Uncovering Hidden Treasures".
(2) Available at: www.triz-journal.com/archives/2001/07/b/index.htm.

Appendix 3
Scale, Microscopes and Nano Structure

- **Scale:**

- A nanometer (nm) is a unit of length in the metric system, equals to one billionth of a metre or one millionth of a millimeter.
  It can be written as 10^{-9} m.
- A micrometer or micron (µm) is one millionth of a metre, or one thousandth of a millimetre.
  It can be written as 10^{-6} m.
- The resolution of human eyes is of the order of 0.1 mm, 100µm.

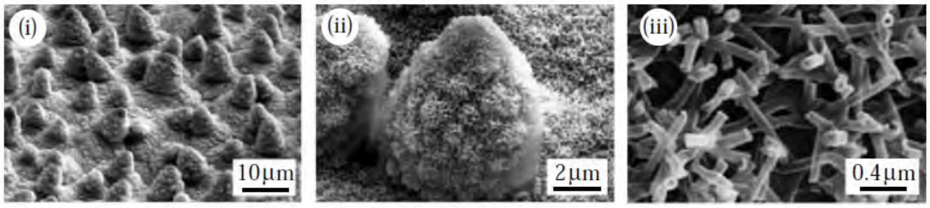

Figure (a.5)
Zooming on the Lotus Leave Showing Three Structural Levels.

The bars on the photos shows the scale
In photo (i): The bar is10 microns- or 1/100 of mm
In photo (ii): The bar is 2 microns-or 2/1000 of mm
In photo (iii): The bar is 0.4 micron- or 4/10000 of mm.

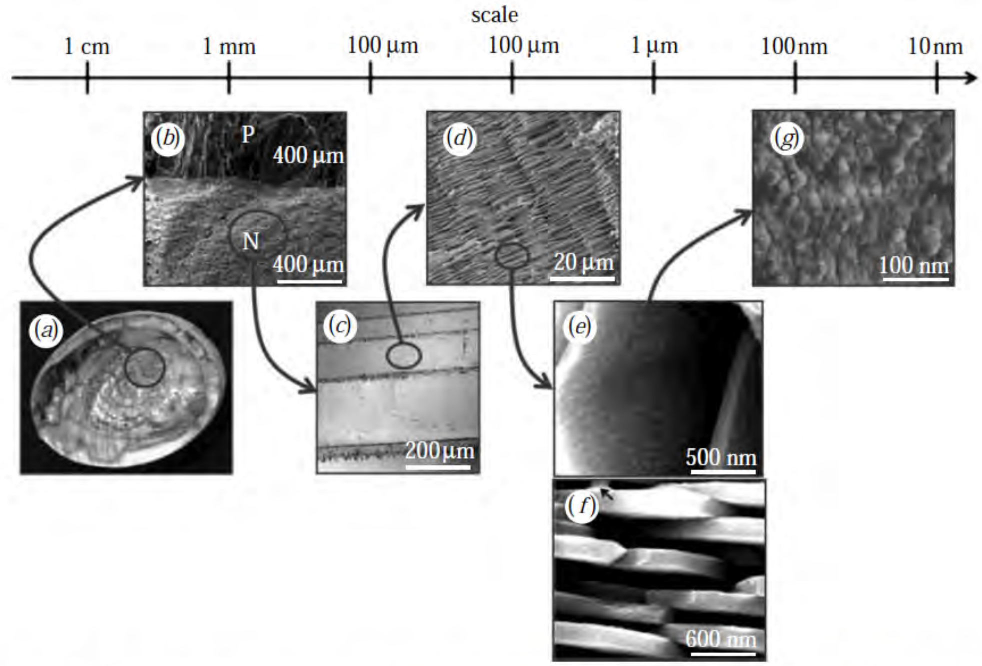

Figure (a.6) Zooming on the Hierarchical Organization in Nacre Showing at Least Six Structural Levels.
The bars on the photos shows the scale, starting from 400 micron in *(b)*, or 0.4 mm, up to 600 nanometer-or sixth of ten thousands of mm in *(f)*.

Microscopes:

- Electron microscopes are scientific instruments that use a beam of energetic electrons to examine objects on a very fine scale.
- The Transmission Electron Microscope (TEM) was the first type of Electron Microscope to be developed. It was developed by Max Knoll and
  Ernst Ruska in Germany in 1931.
- The first Scanning Electron Microscope (SEM) debuted in 1938 (Von Ardenne) with the first commercial instruments around 1965.

o Nano Structure of Butterflies, Responsible for Iridescence.

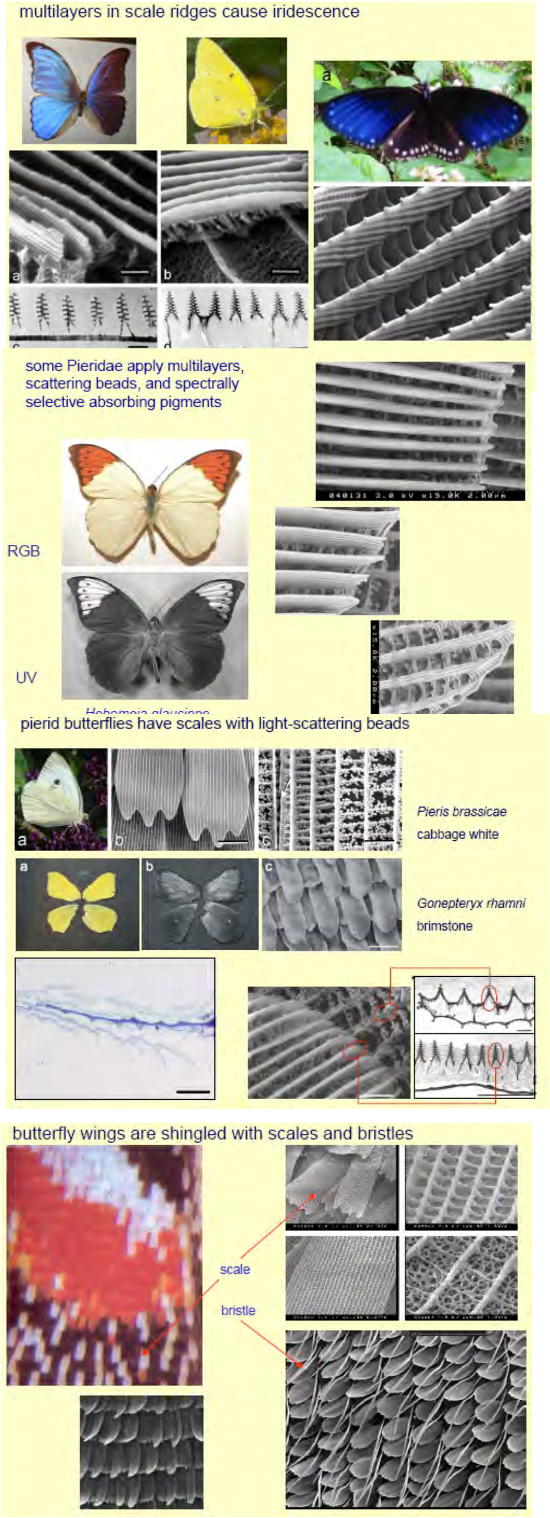

Figure (a.7) Zooming on the Nano Structure of the Butterflies that Causes Iridescence.

Structual Color of Peacock Feathers:

The color of a peacock feather is caused by its complex structure. The coloring changes with the angle of incident light.

Each feather consists of thousands of flat branches. When light shines on the feather, we see thousands of glimmering colored spots, each caused by minuscule bowl-shaped indentations. Stronger magnification reveals microscopic lamellae (thin plate-like layers) at the bottom of the indentations. Just like in butterfly wings, the regular pattern of the lamellas leads to interference phenomena and thus to iridescent colors (1).

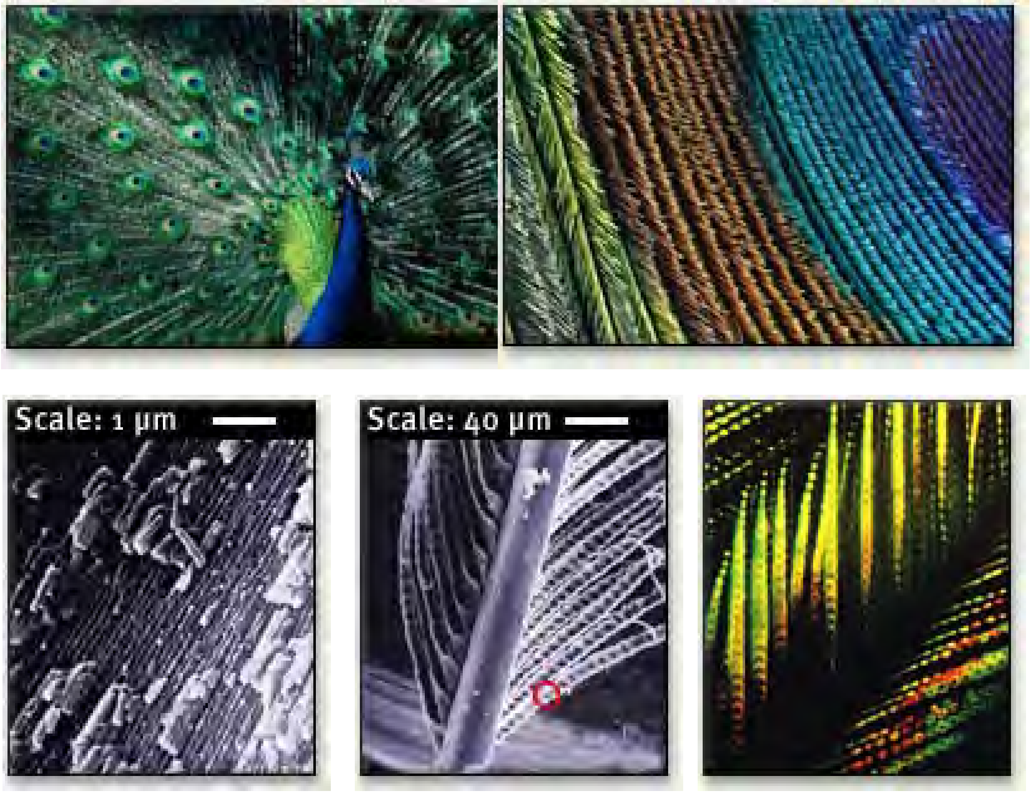

Figure (a.8) Zooming on the Nano Structure of the Peacock Feather
(www.webexhibits.org/causesofcolor/15C.html#sem)

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(1) http://www.webexhibits.org/causesofcolor/15C.html

Appendix 4
Biomimetic Buildings

A set of Biomimetic buildings (1) is viewed here, trying to classify the level in which the mimicry took place. The mimicked organism or phenomenun is also viewed.

• Singapore Art Center

Source of Inspiration: Polar Bear.

Biomimicry Level: Behavior Mimicry in rising and flatting hairs.

Location: Singapore.

Latitude (2): 1°17' N.

Longitude: 103°51'.

Date: 2002.

Designer: DP Architects Singapore and Michael Wellford & Partner, London.

Figure (a-9) Singapore Art Center.
(Williams, 2004)

At Singapore Arts Centre, the skin of the theatres envelopes are composed of thousands of aluminum sunshade pyramids (3) or Lozenges. Those aluminum Lozenges are movable in response to light sensors, providing the building with climate control, much as an animal can raise the hairs on its back (4).

The skin of polar bears is black (5), whereas the white fur is in fact made up of largely transparent tubular bristles (6).

1- The Expression: Biomimetic Architecture appeared in Harris Williams article: "Towards Biomimetic Architecture".
2- Latitudes and longitudes for Singapore is copied from (www.greenwichmeantime.com/time-zone/asia/singapore/map.htm), and for all the following buildings, they will be copied from the same site, and from (www.mapsofworld.com).
3- Sánchez-Alvarez, J., "The Geometrical Processing of the Free-formed Envelopes for The Esplanade Theatres in Singapore".
4- Klimke, H., "The Envelopes of the Arts Centre in Singapore"
5- Previously illustrated in p. 6.
6- Williams, H., "Towards Biomimetic Architecture".

When these bristles are raised, more light penetrates through to the black skin and allows the creature to warm itself efficiently by basking in the sun.

In cooler conditions, the hairs lie flatter, trapping an insulating layer of air. Each hair is operated by a muscle, and the action of that muscle is triggered by a nerve signal. Fig. (a-10) shows a single magnified tubular hair.

The building mimicked the same mechanism, but the nerve signal in the building comes from a photocell rather than a heat sensor (1). Fig. (a-11) shows the movable lozenges, while Fig. (a-12) illustrates the whole building.

Figure (a-10) Polar Bear Tubular Hair.
(www.dailymail.co.uk/sciencetech/article-1082186/Polar-bear-hair-loo-roll-Shark-skin-cheese-grater-Welcome-animal-kingdom-extreme-close-up.html)

Figure (a-11) The Aluminum Lozenges
(Klimke, H. et al.)

Figure (a-12) Physical Model of the Esplanade Theatres
(Sánchez-Alvarez, 2002)

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(1) Williams, H., “Towards Biomimetic Architecture”.

- **Eastgate Shopping & Office Complex:**

Source of inspiration: Ventilation system in termite mounds.

Biomimicry Level: Process mimicry.

Location: Harare, Zimbabwe.

Latitude: 17°43′S.

Longitude: 31°02′E.

Date: 1991.

Designer: Mike Pearce.

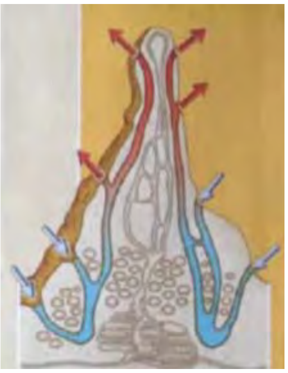

Figure (a-13) Termite Mound Ventilation.
(www.youtube.com/watch?v=dE5hcjAE9fU)

Description:

The building mimics the termite mounds (1) in keeping a relatively constant temperature inside by (2):

1- adopting the same ventilation process
2- Storing coolth at night and release it during the day using the high thermal mass, which was provided by masonry walls and restricted glass areas.

Figure (a-14) Eastgate Center Exterior Shows the Chimneys and Photovoltaics
(Johnston, 2001)

- 32 banks of low and high volume mechanical fans draw filtered air in at low level at the base of the office blocks.
- Vertical ducts allow ‘new’ air to enter each floor void and then enter each office floor below window level.
- Warm ‘old’ air is discharged through wall portholes at ceiling level into further vertical ducts which discharge into the roof void and out through the 48 chimneys, which could be seen in Fig. (a-14).

In plan, the building is correctly oriented with the long axis east-west presenting short gables to the low east and west sun. Precast concrete floor

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(1) Previously viewed at p. 21, and referred to at p. 56.
(2) Johnston, L., "Ant Hill".

cassettes that have projecting teeth into the sub floor air cavity enhance thermal transfer, better than a smooth slab.

By night, ten air changes per hour cool the structure flushing out the previous day's heat.

By day, two air changes per hour, pulled though the structural floor voids, allow the stored 'coolth' to chill the warm incoming 'new' air and then discharge under the windows into the office spaces. Fig. (a-15)

The roof of the two office blocks is a double roof creating a ventilated roof void between the pitched primary roof covered in clay tiles and the flat secondary concrete slab roof, which is the ceiling slab of the upper office floor.

The internal air temperature of the building stays between 24-25°C, while the outside temperatures on a warm summer day are 28°C.

The concrete thermal mass in the floor slabs holds a quite constant temperature of around 20°C in summer and winter and room temperatures do not fall below this.

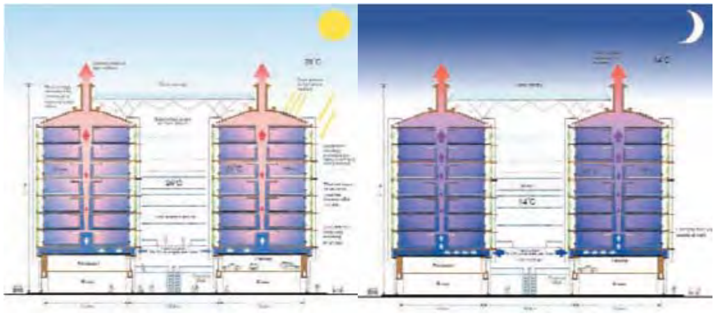

Figure (a-15) Eastgate Complex
Two air changes per hour by day
and ten air changes per hour by night. (Johnston, 2001)

Figure (a-16) The Façade Shows the Exhaust Air Ducts.
(Johnston, 2001)

- **Pearl River tower:**

Source of inspiration: Sponge.

Biomimicry Level: Form mimicry.

Location: Guagzhou, China.

Latitude: 23°05'N.

Longitude: 113°10'E.

Date: 2004.

Designer: Skidmore, Owings and Merrill (SOM).

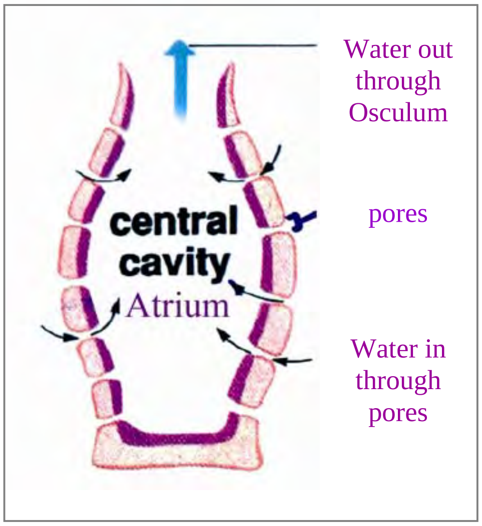

Figure (a-17) Water Flow in Asconid Sponge. *(Pandia)*

The sponges or poriferans (from Latin porus "pore" and ferre "to bear") relies on maintaining a constant water flow through their bodies to obtain food and oxygen and to remove wastes, and the shapes of their bodies are adapted to maximize the efficiency of the water flow.

Figure (a-18) Pearl River Tower *(Frechette and Russell, 2008)*

Water is drawn into the internal cavity or "atrium" through a series of pores in the body wall, and then flows out of the sponge through a large opening at the top called the osculum (1).

The similarity between the Pearl River tower and Porifera outer wall form can be noticed, as this form gives way to water flow in the case of Porifera, and to wind in the case of Pearl River tower.

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(1) Pandya, P., "Porifera: Spicules+Canal System".

Allowing air to pass through the building reduced the forces on the building and hence allowed for reduction in the quantity of steel and concrete used to keep the building stable (1), and the towers curvilinear structure helps to force air through four turbines inlets in the façade as shown in Fig. (a-18).

- The vertical turbine allows for harnising wind from both directions as shown in Fig. (a-19).
- As the air passes through the openings, acceleration takes place and an increased velocity is realized as shown in Fig. (a-20).

Figure (a-19) Vertical Turbine
Harnessing Wind from Both Directions
(Frechette and Russell, 2008)

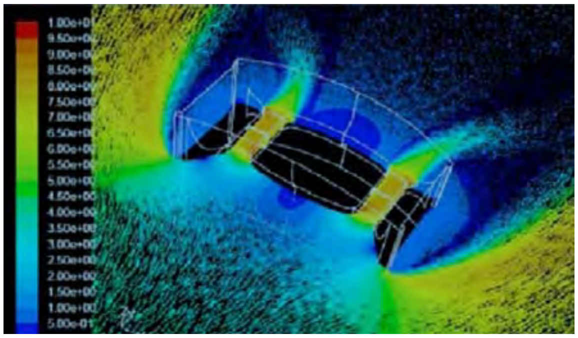

Figure (a-20)
Wind Velocity Vectors at Pearl's Mechanical Floor.
(Frechette and Russell, 2008)

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(1) Frechette, R., and Russell, G., "Towards Zero Energy".

- **Waterloo international terminal:**

Source of inspiration: Pangolin.

Biomimicry Level: Structure mimicry.

Location: York Road, London.

Latitude: 53°58'N.

Longitude: 1°6'W.

Date: 1993.

Designer: Nicholas Grimshaw and Partners.

Program: The International Terminal is an addition to Waterloo train station built in 1922.

Figure (a-21) Pangolin
(Zari, 2007)

Describtion:

The terminal needed to be able to respond to changes in air pressure as trains enter and depart the terminal. The glass panel fixings that make up the structure mimic the flexible scale arrangement of the Pangolin so they are able to move in response to the imposed air pressure forces (1).

Figure (a-22) Waterloo Terminal *(Zari, 2007)*

The two portions of the Waterloo arch are fastened to each other and the platform below with pin connections. The pins allow the arch segments to rotate freely at their connection points (2) as shown in Fig. (a-22).

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(1) Zari, M., “Biomimetic Approaches to Architectural Design for Increased Sustainability”,
(2) www.owlnet.rice.edu/~arch214/waterloo.pdf

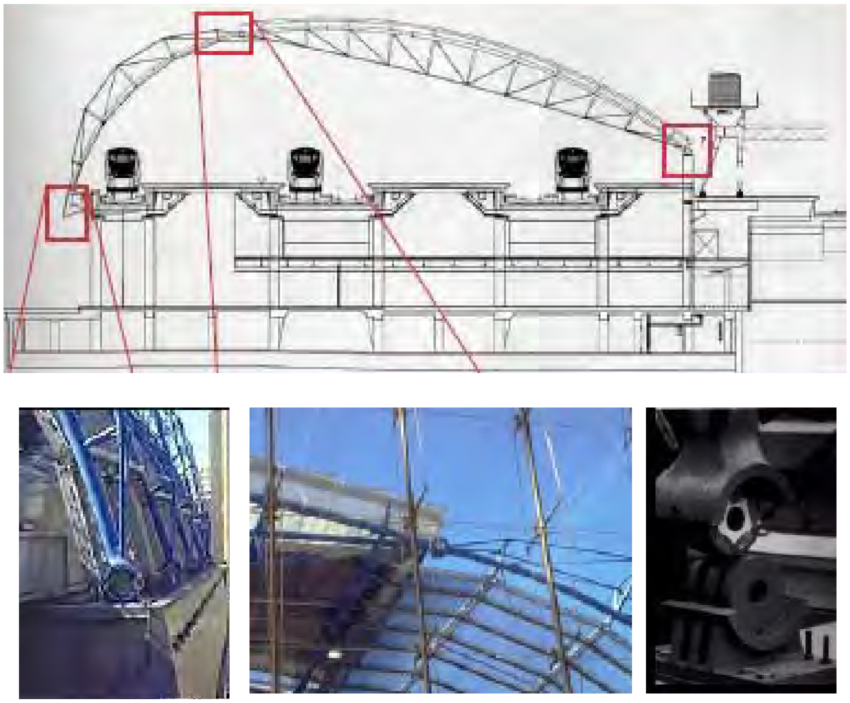

Figure (a-23) Details of Waterloo Terminal
Up: Section shows the pin connections.
Down left and middle: Zooming at pin connections.
Down Right: Pin Joint in detail.
(www.owlnet.rice.edu/~arch214/waterloo.pdf)

Figure (a-24) Waterloo Terminal Exterior.
(www.owlnet.rice.edu/~arch214/waterloo.pdf)

- **Simmon Hall, MIT:**

Source of inspiration: Sponge.

Biomimicry Level: Skin mimicry.

Location: Massachusetts, USA.

Latitude: 42°30'N.

Longitude: 72°0'W.

Date: 2002.

Designer: Steven Holl Architects.

Program: Residence for 350 students.

Figure (a-25) See Sponge
(www.psorialess.com/shoppingcart/products/Bio%252dEthique-Natural-Sponges.html)

Figure (a-26) Simmon Hall
(Astbury, 2003)

Description:

The building mimics the porous skin of the sponge, as the design aimed at allowing penetration of light and air into the heart of the building, this was clear in the building facades that contain over 3000 operable windows, and also in five irregular curvilinear atria in the floor plan that break the monotony of the dormitory corridors.

Large openings exist in main entrances, view corridors, and outdoor terraces. While small openings exist in student rooms, nine windows per each single-occupancy student room (1).

Figure (a-27)
Deep Small Windows
(www.daapspace.daap.uc.edu/~larsongr/Larsonline/Housing_files/simmons_hall.pdf)

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(1) Astbury, J., et al, "Simmons Hall, MIT",

The 'porous' concept achieved the ventilation and lighting goals, it also allowed for views over the nearby Charles River. The depth of the wall, shown in Fig (a-27), naturally shades out the summer sun, while allowing the low angled winter sun in, to help heat the building (1).

The building adopted the "mixed mode" (2) system in air conditioning, which offers low cost maintenance, comparing to the traditional air-conditioning scheme.

In summer, students control natural ventilation using windows and blinds, while in winter, the system delivers pre-heated fresh air to student rooms, shown in Fig. (a-28).

The building is divided into three towers, an air-handled unit (AHU), is mounted on the roof of each tower. Pre-cooled and dehumidified air is ducted from the AHU to each room opening. High and low windows take advantage of the natural rise of warm air within the high-ceilinged rooms.

Figure (a-28) Interior in a Student Room Shows How the "Porous" Wall "Penetrates" Light
(Photo by Andy Ryan. www.web.mit.edu)

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(1) www.designboom.com/portrait/holl_simmonshall.html
(2) Using both natural ventilation and automated tools in air conditioning

- **British pavilion in Seville:**

Source of inspiration: Human.

Biomimicry Level: Process mimicry in sweat-

Behavior mimicry in wearing hats.

Location: Seville, Spain.

Latitude: 37°23'N.

Longitude: 5°58'W.

Date: 1992.

Designer: Nicholas Grimshaw.

Program: Exhibition.

Figure (a-29) Water above the Vertical Facade
(Todorovic, 2005)

The design mimics the unconcious behavior of the human body in sweating, through evaborative cooling, and also mimics the concious behavior of man wearing a hat (1).

Movable protection on the roof is put according to the momentary sun location, controlled by “building’s intelligence”, and help the metal panels on the roof from getting too hot.

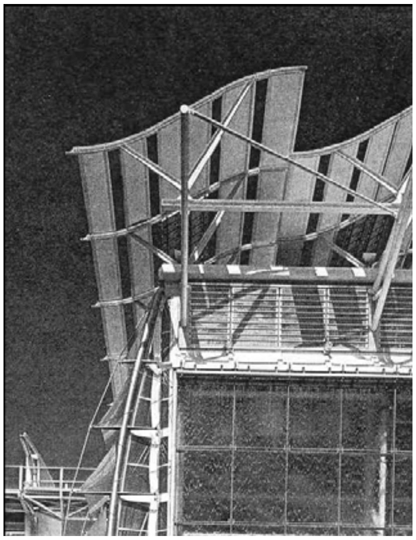


Figure (a-30) Solar “Hats” on the Roof of the British Pavilion at EXPO 1992.
(Todorovic, 2005)

---

(1) Todorovic, B., “Building’s Imitation of a Human Body’s Thermal Behavior”.

- **30 St Mary Axe (Swiss Re Building):**

Source of inspiration: Glass Sponge, (genus: Euplectella).

Biomimicry Level: Process mimicry in water currents movement.

Location: London.

Latitude: 51°36'N.

Longitude: 00°05'W.

Date: 2003.

Designer: Norman Foster.

Program: Swiss Re building.

The glass sponge shown in Fig. (a-31), sucks water into its body at the base and circulates it upwards, extracting nutrients as it goes, until it is expelled from a vent at the top.

Williams states that the building circulates air inside rather as the sponge pumps water (1), drawing it in low down, and allowing it to rise as it is warmed through the dramatic spiral atriums that slice through the floors of the building (2).

Figure (a-31) 30 St Mary
(Williams, 2004)

Figure (a-32) Glass Sponge
(www.killerinourmidst.com/Early%20Triassic1.html)

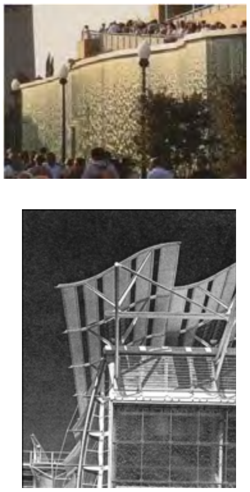
1- Williams states another analogy, that the sponge is anchored to the seabed with currents swirling round it. Similar to the air currents that the curving shape of the building ameliorates round its base.

2- Williams, H., “Towards Biomimetic Architecture”.

Table (a-2): A List of Some Biomimetic Buildings:

No.	Building	Source of Inspiration	Level of Mimicry	The Feature	Other Overlapping Levels
1	 Singapore Art Center	 Polar bear	Behavior Mimicry in rising and flatting hairs.	The aluminum Lozenges, covering the theatre, are movable in response to light sensors	Skin mimicry
2	 Eastgate Shopping and Office Complex	 Termite mounds.	Process mimicry	The building keeps a relatively constant temperature inside, using high thermal mass and stack effect	---
3	 Pearl River Tower	 Sponge	Form mimicry	The building gives way to wind flow.	---
4	 Simmon Hall	 Sponge	Skin mimicry	The porous envelope achieved the ventilation, lighting and view goals	---

Table (a-2) continued:

No.	Building	Source of Inspiration	Level of Mimicry	The Feature	Other Overlapping Levels
5	 30 St Mary Axe	 Glass Sponge	Process mimicry in water currents movement	The building circulates air inside	---
6	 Waterloo international Terminal	 Pangolin	Structure mimicry	Flexible glass panels are able to move in response to the imposed air pressure forces.	---
7	 British pavilion in Seville	Human when he sweats	Process mimicry	Evaborative cooling	---
		Human when he wears a hat	Behavior mimicry	Movable protection on the roof	---

Appendix 5

More Photos for the Lotus Temple

Figure (a-33) The Lotus Temple from Inside.
(*http://www.sahbaarchitect.com/flash.html*)

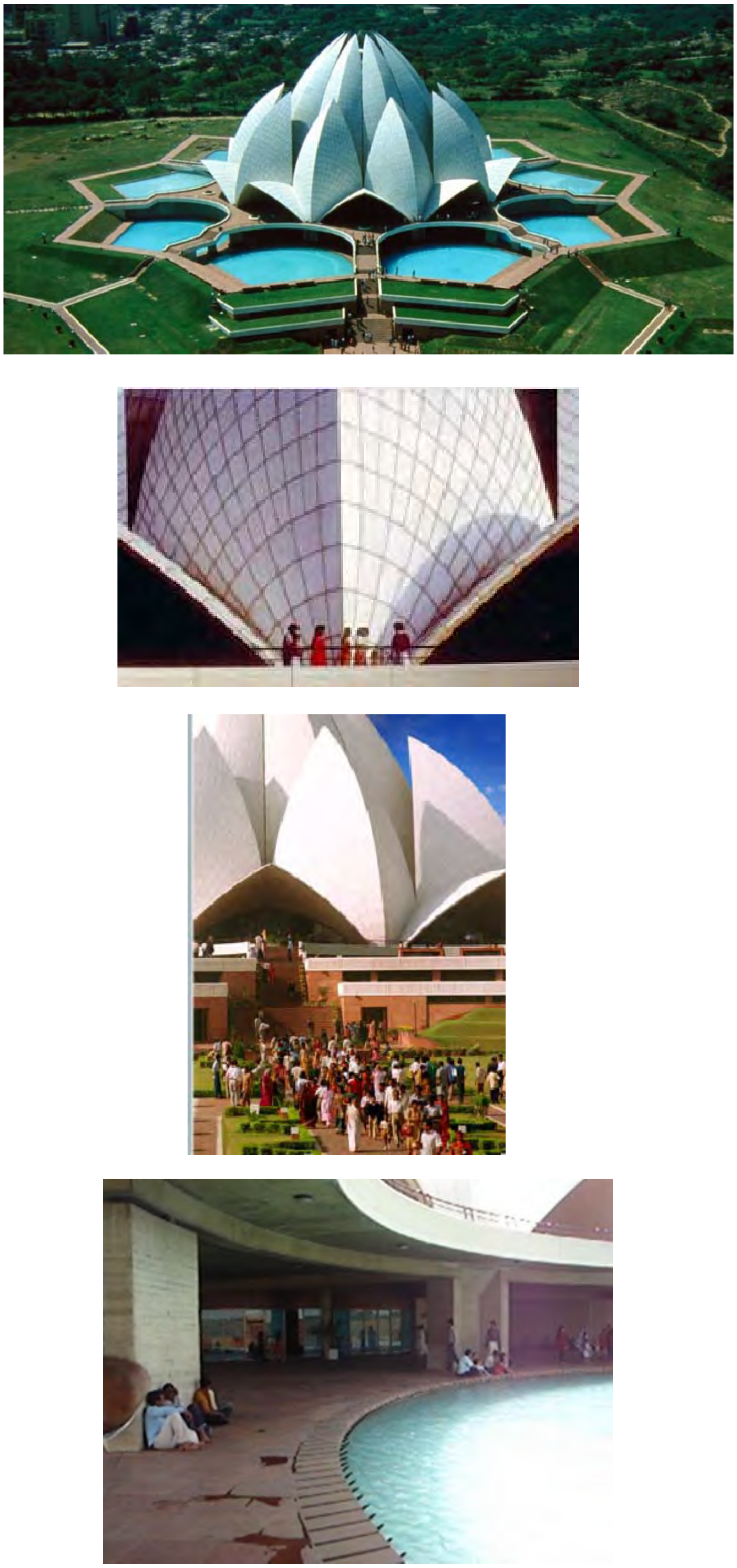


Figure (a-34) The Lotus Temple from Outside.
(http://www.sahbaarchitect.com/flash.html)

Appendix 6
Life's Principles

Fig.(a-35) shows a comprehensive review for nature design principles, that are titled “Life Principles".

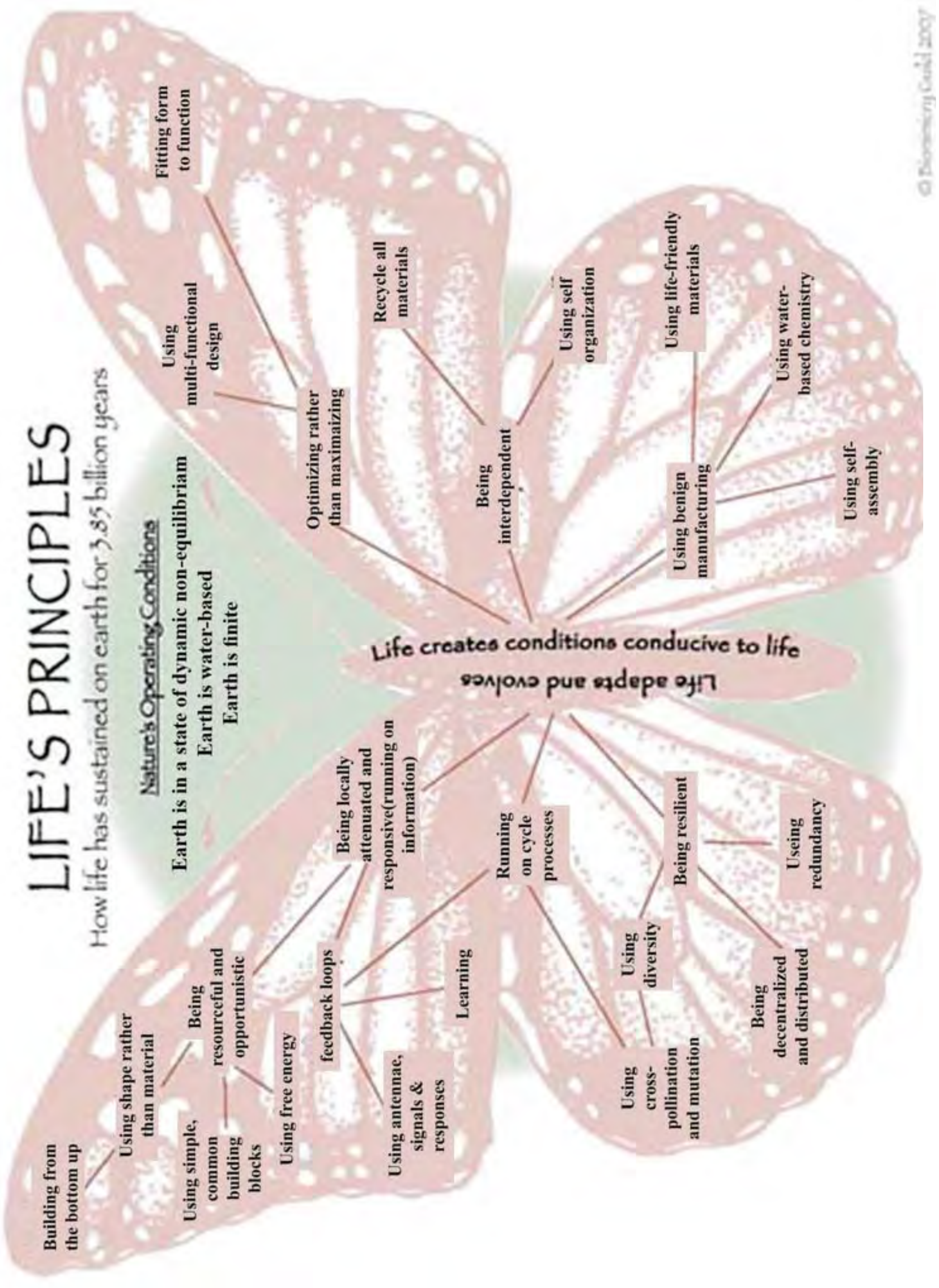


Figure (a-35) Life's Principles
(www.biomimcrvauild.com)

Appendix 7
Biomimcry Design Spiral.

Fig. (a-36) is a comprehensive figure for biomimicry design spiral, which was viewed at p. 97.

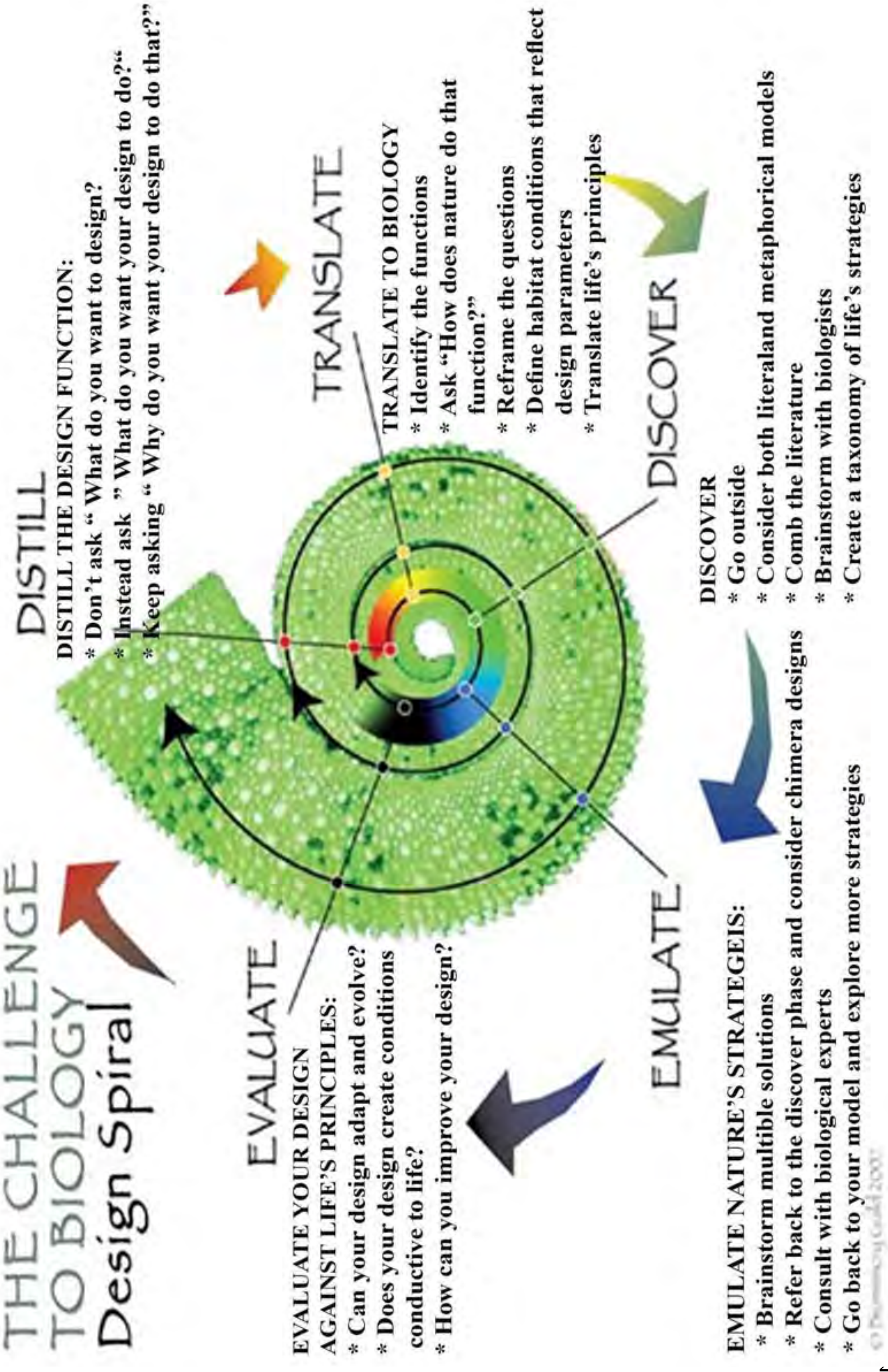
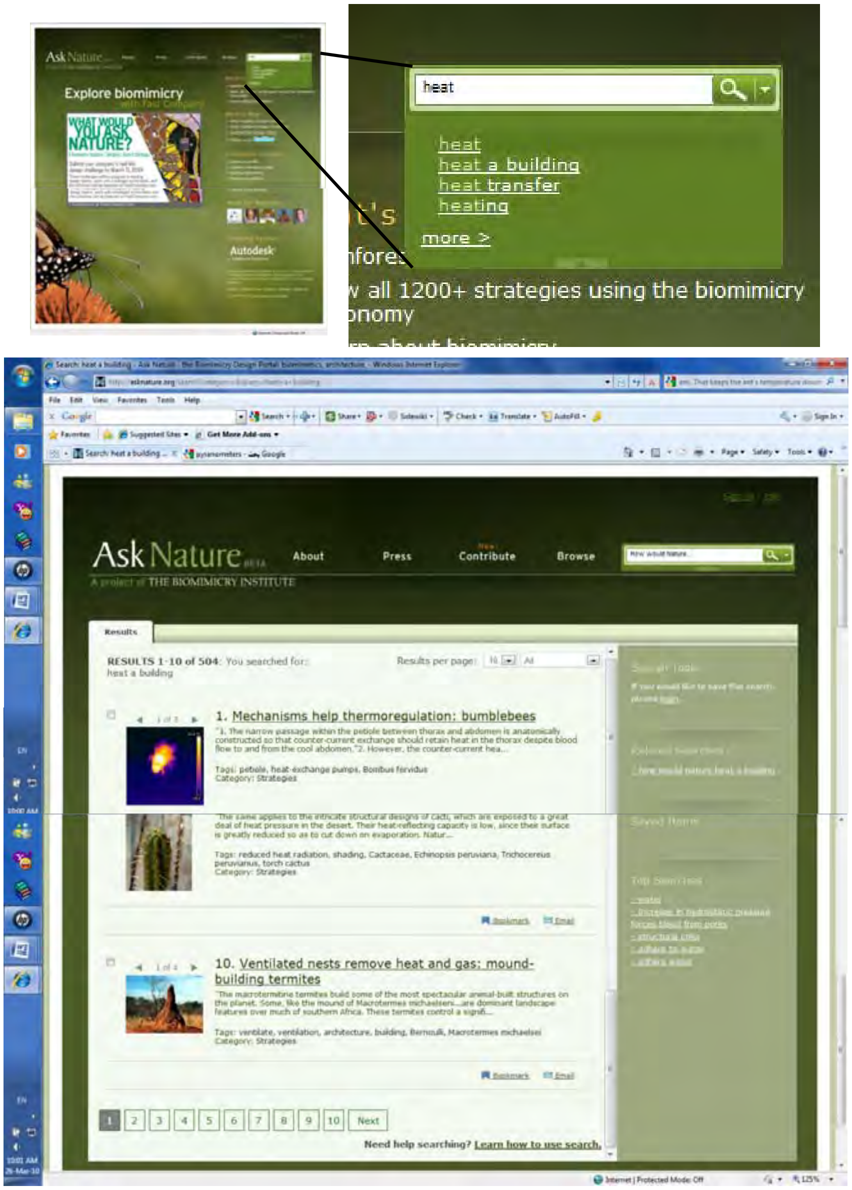


Figure (a-36) Biomimicry Design Spiral
(Biomimicry News Letter, 2006)

Appendix 8
Database Project for Nature Efficiency.
(www.asknature .org)

The user writes the key word in the specified space. For example, Heat, cool, isolate…etc. The organism or ecosystem that best performs the function then appears with breif data.

The web site also offers scientific refernces for the mentioned data.



RESULTS 1-10 of 504: You searched for: heat a building

1. Mechanisms help thermoregulation: bumblebees

"1. The narrow passage within the petiole between thorax and abdomen is anatomically constructed so that counter-current exchange should retain heat in the thorax despite blood flow to and from the cool abdomen."2. However, the counter-current hea...

Tags: petiole, heat-exchange pumps, Bombus fervidus
Category: Strategies

"The same applies to the intricate structural designs of cacti, which are exposed to a great deal of heat pressure in the desert. Their heat-reflecting capacity is low, since their surface is greatly reduced so as to cut down on evaporation. Natur...

Tags: reduced heat radiation, shading, Cactaceae, Echinopsis peruviana, Trichocereus peruvianus, torch cactus
Category: Strategies

10. Ventilated nests remove heat and gas: mound-building termites

"The macrotermitine termites build some of the most spectacular animal-built structures on the planet. Some, like the mound of Macrotermes michaelseni...are dominant landscape features over much of southern Africa. These termites control a signifi...

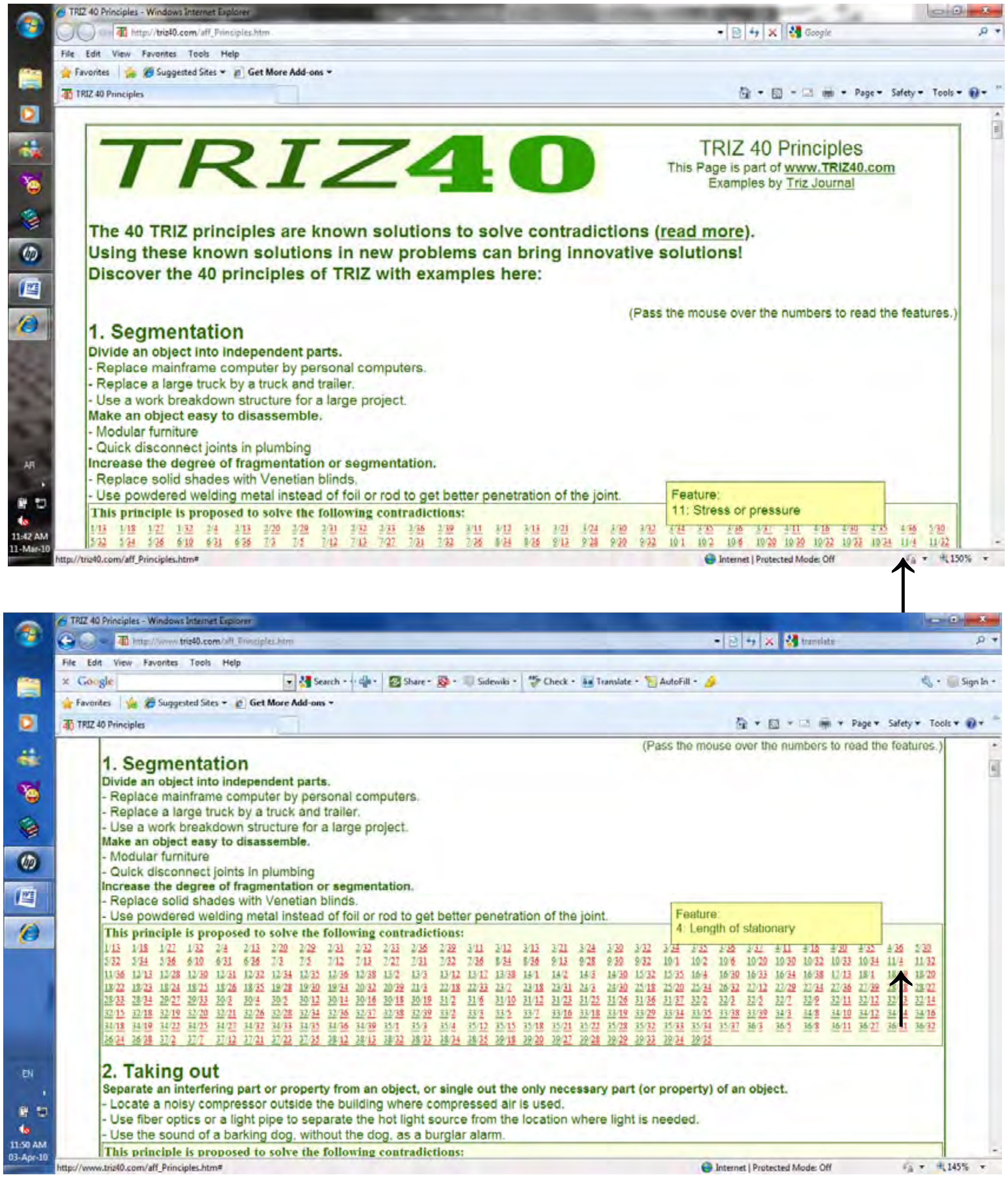
Tags: ventilate, ventilation, architecture, building, Bernoulli, Macrotermes michaelsei
Category: Strategies

Need help searching? Learn how to use search.

Figure (a.37) Interface of the Website: (www.asknature.org).

Appendix 9
The Web Page of the 40 Inventive Principles by BioTRIZ Journal (http://triz40.com/aff_Principles.htm)

- Last accessed 8-10-2010
- Passing the mouse over the numbers views the contradicting features that may be solved using the inventive principles.



TRIZ 40 Principles
This Page is part of www.TRIZ40.com
Examples by Triz Journal

The 40 TRIZ principles are known solutions to solve contradictions (read more).
Using these known solutions in new problems can bring innovative solutions!
Discover the 40 principles of TRIZ with examples here:

(Pass the mouse over the numbers to read the features.)

1. Segmentation

Divide an object into independent parts.
- Replace mainframe computer by personal computers.
- Replace a large truck by a truck and trailer.
- Use a work breakdown structure for a large project.

Make an object easy to disassemble.
- Modular furniture
- Quick disconnect joints in plumbing

Increase the degree of fragmentation or segmentation.
- Replace solid shades with Venetian blinds.
- Use powdered welding metal instead of foil or rod to get better penetration of the joint.

This principle is proposed to solve the following contradictions:

Feature:
11: Stress or pressure

Feature:
4: Length of stationary

2. Taking out

Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.
- Locate a noisy compressor outside the building where compressed air is used.
- Use fiber optics or a light pipe to separate the hot light source from the location where light is needed.
- Use the sound of a barking dog, without the dog, as a burglar alarm.

This principle is proposed to solve the following contradictions:

Figure (a.38) Interface of the Web Page: (http://triz40.com/aff_Principles.htm).

Appendix 10
E-Mails

This is a copy of four Emails that were sent for consultation, in different phases of this work.

Two Emails were sent to Dr Julian Vincent (1), Professor of Biomimetics, at the Centre for Biomimetic and Natural Technologies, University of Bath. Who had formed, with his small team, the BioTRIZ.

The other two emails were sent to Dr Salmann Craig (2), School of Engineering and design, Brunel University. He had managed to use BioTRIZ to design a kind of a biodegradable concrete formwork, and a kind of roof insulation that let infra red radiation passes, and hence offers radiative cooling. Salmann works for “Buro Happold”, a professional services firm providing planning, management and consulting services for all aspects of buildings, infrastructure and the environment.

The reason why these emails were viewed that their reply may enlighten the way for further research steps.

The Emails are:

1. Email to Julian Vincent, on 2009, asking for resources.
2. Email for Julian Vincent, on 2010, revising the validity of the conflict forming.
3. Email for Salmann Craig, on 2010, asking why he expressed the heat gain by loss of Energy.
4. Email for Salmann Craig, on 2010, revising the validity of the conflict forming.

---

(1) The co-author of “Biomimetics: Its Practice and Theory”. He was presented in the introduction, at p. XXXIV.

(2) His research was viewed at p. 141.

1. Email to Julian Vincent, on 2009, Asking for Resources:

a) Email

On 11 May 2009, at 05:36, Ayat Al jawhary wrote:

Dear Mr. Vincent

My name is Ayat, I am an Egyptian architect. and I'm working on my master thesis on Biomimimetics and architecture.

I hope that you could help me find your article:

Architecture and biomimetics: closing the gap. M Beavan & J FV Vincent (2004).

I'm also trying to find out how architects can use BioTriz to reach environmental friendly solutions in architecture. I hope that you could guide me to useful references.

Thanks a lot for your time

Yours Ayat

b) Reply:

Re: Biomimetics and architecture
Monday, May 11, 2009 4:19 AM
From: "Julian Vincent" <j.f.v.vincent@bath.ac.uk>
To: ayattt23@yahoo.com

I don't know that the chapter with Mike Beaven is much use, and anyway I don't have a copy of it. Far better is a recent study by a young engineer working with Buro Happold. I was the external examiner for his thesis. I attach one of his papers (1) as a starting point for you.

Julian Vincent

---

(1) The paper attached was: Craig, Salmann, et al., "BioTRIZ Suggests Radiative Cooling of Buildings Can Be Done Passively by Changing the Structure of Roof Insulation to Let Longwave Infrared Pass".
Dr. Vincent was actually referring to Dr. Salmann Craig.

2. **Email for Julian Vincent, on 2010, Revising the Validity of the Conflict Forming**.

a) Email

On 25 Jan 2010, at 13:54, Ayat Al jawhary wrote:

Dear Mr Vincent:

I sent you an E-mail few months ago and I received a generous reply.

I'm an Egyptian architect and I'm still working in my master thesis on Biomimicry, BioTRIZ and architecture. And now I'm in the applying phase. But I still have few questions, if your time allows:

In your paper "Biomimetecs its practice and theory "you've set the methodology of Biomimetics:

In page 479, Step (ii), we read:

Find the functional analogy in biology (look into the PRIZM) or go to the biological conflict matrix (table 2); The question is: What is the first alternative here (the PRIZM)? Is it (table 1)?

I thought that table 2 is the only one that relates to Biology.

In TRIZ, we find the solution for the contradiction between Weight of moving object(1) vs. Stability of the objects composition(13) is: IP 1-35-19-39. While in the "PRIZM matrix that is derived from standard TRIZ matrix." We find the solution for the contradiction between Substance and structure is only: IP 27.

I didn't understand why? I thought that the result between substance and structure in the PRISM matrix will be: all the inventive principles in TRIZ-that are resulted from all the contradicting features that lie under the operational fields:"substance and structure", instead I found only one inventive principle. Could you please explain?

I'm trying to find Biomimetic solution to the following question:

"How to regulate the heat gain through the building envelope?"

How can the envelope protect the internal space from the undesired heat/cold outside without being over heated cooled?

The only contradiction I formed till now was:

Stress vs. Object affected harmful (and/or generated harmful-as the roof gets over heated or cooled, and so, heat conduction to the living spaces occurs).

I find some difficulty in forming further contradictions.

I thought that the contradiction (that I found in Salmann Craig research):

“Temperature vs. loss of energy” might also be correct

Are the two contradictions really express the question?

Is it incorrect that I’m trying to use BioTRIZ to answer such a general not specific problem? As we have chosen to deal with the building envelope in general, and according to this, we have chosen the word “regulate” instead of” reduce” or ”increase“ the heat gain to make the problem general to cover both hot and cold climates.

Do you see that BioTRIZ should only be used to solve specific problems? Or I can still use it to find inventive (general problem) solutions?

Is it a must that we look up our contradictions in TRIZ first? Why don’t we just apply to BioTIZ since we are concerned with Biomimicry?

Thanks a lot for your time

Ayat Al-Jawhary

b) Reply:

Monday, January 25, 2010 5:07 PM

From: "Julian Vincent" <j.f.v.vincent@bath.ac.uk>

To: "Ayat Al jawhary" <ayattt23@yahoo.com>

Cc: "Olga Bogatyreva" ensob@bath.ac.uk

Thanks for your letter.

In general, the more specific you can make the statement of your problem, the easier it is to use TRIZ (or BioTRIZ) to find the answer. The PRIZM matrix is our 6 x 6 condensed version of the full matrix; we invented it because we couldn't get enough biological data for a full 39 x 39 matrix, and we needed to have a good comparison.

There is no guarantee where you will find an answer, but does that really matter? You are trying to find a solution which conforms to certain criteria, such as low energy input, easy recycling, etc., and that's all that really matters. Are you sure you are defining your problem properly? When we teach a 3-day course on TRIZ we spend the whole first day on defining the problem.
I'm copying this to Olga, who designed the PRIZM matrix. She will be able to answer your more technical questions below.

Best wishes
Julian Vincent

3. Email for Dr. Salmann Craig, on 2010, Asking Why he Expressed the Heat Gain by Loss of Energy.

a) Email

From: Ayat Al jawhary [mailto:ayattt23@yahoo.com]
Sent: 25 January 2010 09:46
To: Salmaan Craig
Subject:

Dear Dr. Salmann Craig

I'm an Egyptian architect working on my master thesis in Biomimicry, BioTRIZ and Architecture.

I'm in the application phase and I'm trying to find biomimetic solutions for the question: How could we regulate the heat gain through the building envelope?

I've referred to your research: TWO NEW ENVIRONMENTAL BUILDING TECHNOLOGIES, ONE NEW DESIGN METHOD: INFRARED TRANSPARENT INSULATION, BIODEGRADABLE CONCRETE FORMWORK AND BIOTRIZ
and I have the following questions if your time allows:
1-Why Did you form the contradiction as: Temperature vs. Loss of energy?

I mean why did you express the sentence: "without counterproductive energy inputs from the super system" by loss of energy? Did you mean that: (loosing heat) by the building mass is (worsening)?

2- in my trial to find biomimetic solution for the underlined problem above, I formed the following question and contradiction :
the formed question is: How can the envelope protect the internal space from the undesired heat/cold outside, without being over heated /cooled?
The formed contradiction is: Stress vs. Object affected harmful (and/or object generated harmful).
Now I'm trying to form a second and a third contradiction.
Could your contradiction (temperature vs. loss of energy) express the same question?

I'm asking this because the temperature here would express the temperature INSIDE the building envelope not the temperature of the envelope itself.

Thank you for your time
Best regards.
Ayat Al Jawhary

b) Reply:

RE:
Monday, January 25, 2010 5:21 AM
From: "Salmaan Craig" <Salmaan.Craig@BuroHappold.com>
To: "Ayat Al jawhary" <ayattt23@yahoo.com>

Hello Ayat,

1. I was framing the problem around the heat balance (ignoring latent exchanges). So the radiator (or surface of the mass) temperature is a balance between radiative energy ‘losses’ to a cold sky and the solar

and sensible ‘gains’. But in this scenario, I define the radiative ‘losses’ as useful, and the solar and sensible ‘gains’ as harmful. So letting in the solar and sensible flux is harmful, and hence a ‘loss’ of useful energy. Of course, strictly speaking**, it’s not a loss, just an unhelpful balancing.** (1) But the problem framing is still valid.

2. Are you framing the radiative cooling conflict at the building level? I framed it at the material/component level, so it was more specific. The way you frame it is very general to many building types and climates (2).

Regards,

Salmaan

---

(1) Dr Craig used the feature “loss of energy” to express the “unhelpful balance”.

(2) I believe that as a start to present and practice the BioTRIZ, it could be accepted to form a general task framing that may express and serve **many types of buildings and climates** as Dr Craig stated. This is because this work aims at exploring the biomimetic methods, and had ended with presenting the BioTRIZ as an applicable method, and interpreting the resulted inventive principles from an environmental architectural point of view.
So to present a model, this model is accepted to be general.

4.Email for Dr. Salmann Craig, on 2010, Checking the Validity of the Conflict Forming:

a) Email

From: Ayat Al jawhary [mailto:ayattt23@yahoo.com]
Sent: 25 January 2010 14:16
To: Salmaan Craig
Subject: Thank you

Dear Dr Salmann Craig

Thank you for the generous instant reply

In fact, yes I'm framing the problem of building envelope form and characteristics in a general way, we have chosen to deal with the building envelope in general, and according to this, we have chosen the word "regulate"
instead of" reduce" or "increase" the heat gain to make the problem general to
cover both hot and cold climates.
Do you see that BioTRIZ should only be used to solve specific problems? Or I can still use it to find inventive (general problem) solutions?

once again, thank you for your time

Ayat Al Jawhary

b) Reply:

RE: Thank you
Monday, January 25, 2010 11:25 AM
From: "Salmaan Craig" <Salmaan.Craig@BuroHappold.com>
To:"Ayat Al jawhary" <ayattt23@yahoo.com>

Hi Ayat,

With TRIZ, the more accurate problem formulation, the better the results. This is because:

1. By definition you understand the problem better
2. It will be clearer what the solution principles ‘mean’ in the defined context

With BioTRIZ it is a bit easier – you just need to be sure what meta-categories count – for instance, is it ‘energy’ vs. ‘energy’, or ‘energy’ vs. ‘substance’. You could repeat the process at different system levels too – component, building etc.

I would suggest using looking up the TRIZ functions database if you want a list of effects or phenomena that could be harnessed to ‘regulate temperature’ or ‘heat’ or ‘cool’. See ***http://function.creax.com***/ or one of several TRIZ books. See also Steven Vogel’s ***‘Living in a Physical World’*** series in the Journal of Bioscience, especially parts ***III*** and ***IV***

Hope this helps
Salmaan

"محاكاة الطبيعة"
في التصميم المعماري البيئي
استكشاف مفهوم ومنهجيات التصميم المعماري البيئي المستلهم من الطبيعة

إعداد

م/ آيات عبد الرحيم الجوهري أحمد شتا

رسالة مقدمة إلى كلية الهندسة - جامعة القاهرة

كجزء من متطلبات الحصول على

درجة الماجستير

في

الهندسة المعمارية

كلية الهندسة، جامعة القاهرة
الجيزة، جمهورية مصر العربية
يوليو ٢٠١٠

"محاكاة الطبيعة"
في التصميم المعماري البيئي
استكشاف مفهوم ومنهجيات التصميم المعماري البيئي المستلهم من الطبيعة

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كجزء من متطلبات الحصول على درجة الماجستير

في الهندسة المعمارية

تحت إشراف

أ. د. بهاء الدين حافظ بكري	**أ. د. أحمد فكري**
الأستاذ بقسم الهندسة المعمارية	**الأستاذ بقسم الهندسة المعمارية**
كلية الهندسة، جامعة القاهرة	**كلية الهندسة، جامعة القاهرة**

كلية الهندسة، جامعة القاهرة
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كجزء من متطلبات الحصول على درجة الماجستير

في الهندسة المعمارية

يعتمد من لجنة الممتحنين:

الأستاذ الدكتور بهاء الدين حافظ بكري مشرفا رئيسيا

الأستاذ الدكتور أحمد أحمد فكري عضوا

الأستاذ الدكتور محمد مدحت درة عضوا

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