An Adaptable Living Machine for Contemporary Nomads

People who are willing / need to be continuously moving to different locations for
- exploring
- experiencing
- work

An unit that allow high level of mobility and satisfying a degree of living comfortability

To change from one place or position to another

A house, apartment, or other shelter that is the usual residence of a person
Graduation Project's Title:

**HOME ON MOVE!**

An Adaptable Living Machine for Contemporary Nomads
**Declaration**

I declare that this research report is my own original work, and that all sources that I have consulted have been duly acknowledged. According to the research topic, some information might not only be based on literature source but web source. Information relating to most updated technologies and experimental research results might vary according to providers’ modification. Hereby, I declare that all web based reference source contained in this report are provided with sources’ owners’ information and relative http links.

I further declare that this work has not previously been submitted by me for a degree at the Delft University of Technology or any other institution.

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Date: 3rd June, 2013
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Introduction

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THE FASCINATION

For centuries, human fantasy on futuristic living modes would be highly mobile, in all means of transportation medium (land, ocean, sky). This idea has been visualized in various forms in media press, for example films, animations and novels.

The image below was captured from a Japanese animated movie entitled “The Howl’s moving castle” by Hayao Miyazaki. The moving creature presented in the image is a castle with legs and mouth. In the movies, this castle is able to walk, swim and fly like an animal. The message behind the image reflects the fantasy of human’s futuristic dwelling, the most secure and personal space - “your home” always move with you to different locations, a personal space that provides all necessary functional space and offers high mobility.

From the scene, the castle was composed by many unusual components of a building, which also reflects the humans imagination on how **Machine** (Steam engine, pulley system), **Organism** (mouth, legs, tail) and **Architecture** (rooms, windows) can combine as a whole, “**Living Machine** “.

Japanese animated fantasy film
” Howl's moving castle “
By Hayao Miyazaki
http://24.media.tumblr.com/tumblr_kyc461Id8111pq221o1_500.jpg
We live in an Era that emphasizes movement

We live in an age characterized by movement, by the increasingly present voice of globalization urging a shift towards permeable boundaries, trans-nationalism and the free movement of capital. The fact that getting a permanent job, owning an apartment, marriage and family has become the norm as the typical life process of human. Meanwhile, the globalized world changed human life style. The closely linked connection between different countries shaped human living into a new trend, many people required to live in different location in certain period of time for different purpose, moving for a job is often required, a truly global community.

The improved technologies on transportation

The improvement of technologies in the past century has been maximized human's mobility, people can move to most places on earth by different mean of transportation. Since the first industrial Revolution, the first steam engine has been introduced and the revolutionary '60s anticipated a time when architecture would have to respond to the mobility, fast pace, and transformability of a globalized world. As the technology has been rapidly improved, nowadays transportation is much faster, efficient, comfortable and affordable than the past decades. Figure (1) to (4) show an annual record of different transportation paths on earth. From the images, it reflects the fact that with the help of contemporary automobile development people are able to travel almost all locations on earth by different means of transportation. Yet, the topic "mobility" in Architecture seems to be slowly developed compared with contemporary automobile machines.

Fig. (1) World travel map based on time
http://1.bp.blogspot.com/_F_ZyVOpuO7M/TQ5-iVqyOFI/AAAAAAAACCM/hpjlZqsOn-k/s640/travel-time-map600x295.jpg

Fig. (2) World Ocean traffics Network
http://www.newscientist.com/data/images/ns/cms/mg20227041.500/mg20227041.500-5_1000.jpg

Fig. (3) World Rivers Network
http://www.newscientist.com/data/images/ns/cms/mg20227041.500/mg20227041.500-6_1000.jpg

Fig. (4) World Railways Network
http://www.newscientist.com/data/images/ns/cms/mg20227041.500/mg20227041.500-4_1000.jpg

Fig. (5) World Highways Network
http://mrbarlow.files.wordpress.com/2009/04/the-worlds-roads.jpg
The contemporary nomads
As a result of globalization and improvement of technologies, humans habitation is no longer limited in certain locations. The result is significant and deeply affect our social network and daily life. People may continuously travel because of job requirements, social connection or other personal reasons. The term "contemporary nomads" can be defined as "people who are willing / need to be continuously moving to different locations for exploring, experience and work". One example of this group of people may be a documentary film crew working for global media, like national geographics or discovery channel.

Portable / mobile architecture - caravan
Due to the emphasis on movement in contemporary life, Architects started to explore the new nature of architecture, the "mobility in architecture". A home and a dwelling are fundamental spaces for physical survival and are important to individual and social identification for all living beings. We may say the domestic architecture would be the generic type of architecture in our architectural history. Meanwhile, it is also a mental place indispensable for safety and protection, living space is also a paradigmatic area, a vehicle for identity. It can reveal our experience and our unconscious, communicate our aspirations and desires, demands and emergencies and our vision of the world. That is the reason why most of the experimental architectural design are design for dwelling, like a caravan.

Although architecture has been always presented as an object that creates various spatial qualities at certain fixed location. Here are couple of examples that demonstrates the possibilities of architecture being movable. We usually catagerize them as "mobile architecture" or "portable architecture".

The topic of contemporary "mobile architecture" or "portable architecture" can be traced back to the late 1920s' airstream trailer designed by Wally Byam (figure (8)) and Buckminster Fuller's Dymaxium house.
PROJECT STATEMENT

In order to achieve the idea of mobility, it is necessary to first consider and attain the idea of adaptability.

Mobility & Adaptability

The design and development of Movable / Portable Architecture nowadays already demonstrate a remarkable success. However, there is still potential to make a breakthrough in the design of these type of architecture. Caravan can be regarded as a combination of Architecture and Automobile. People takes caravans for camping during their vacation, but the location of the camp is restricted. This may due to the limitation of supporting facilities or one of the most important issues are - “Adaptability”. The adaptability of a caravan is related to the climatic and contextual conditions limitaion, therefore people are not allowed to travel anywhere freely.

Let's take a 4-Wheel-Drive vehicle as an illustration. 4WD shows a remarkable performance in adapting to different climatic and geographical conditions and even shows a great performance in extreme scenarios. However, the 4WD design only demonstrate its high mobility in different climatic and geographical conditions, but it is definitely not a comfortable space for people to live. Therefore in order to achieve the idea of mobility, it is necessary to first consider and attain the idea of adaptability.

Figure (9) demonstrated the design sequence differences of type of architecture.

For a typical architecture, we usually carry out research and analysis at a specific location (measurement), providing an idea or solution to generate the design (solution & design) and follow with construction of the architecture (situate). It is a result of architectural design functioned at specific location, orientation and surrounding condition.

Where a responsive architecture would have a slightly difference approach, after the architecture has been completed, the architecture itself keep on carrying out measurement and reacts to the changing environment continuously by different means of building systems. For example the solar responsive facade at Institut du Monde Arabe designed by Jean Nouvel. The facade responds to the changing incident sunlight angle by the mechanical controlled shading devices.

On top of just being responsive, an adaptable architecture would also react to surrounding condition based on user’s decision,

Typical Architecture

![Typical Architecture Diagram](image)

Responsive Architecture

![Responsive Architecture Diagram](image)

Adaptive Architecture

![Adaptive Architecture Diagram](image)

Fig. (9)
Comparison on the functional sequence of different type of architecture
In order to create a Portable Architecture that can be situated well in all environments, this object should adaptable to all:

- **climatic**, 
  - temperature, humidity, precipitation, solar intensity, ...


- **contextual**, 
  - urban context, rural, forest, desert, ...

- **transportation conditions** 
  - requirements, methods, ...

- **and** 
  **user requirements** 
  - daily routine, occupation, personal preference, ...
PART B
Research Set Up

Research Planning
  1.1 Research Question
  1.2 Research Tool

Research Field
  2.1 Warm-blooded Vertebrate's Integumentary System
  2.2 Integumentary Organs
  2.3 Interaction between Different Systems
CHAPTER 1  RESEARCH PLANNING

GRADUATION PROJECT FLOW

Based on the fascination of Mobile Living Units, it was found that the existing movable / portable architecture is not capable to place in different environments. Adaptability is the main factor that govern the ability of the mobile / portable architecture whether it can withstand in such extreme environmental conditions or not. Research on Biomimicry is carried out, as to investigate how the unit adapt to the changing external environments and how it establishes a comfortable living condition for the user in relation to physical conditions, indoor quality regulation, insulation and sensation.
RESEARCH QUESTION

One of the important topic for designing a building that can be situated well in different locations is how the building can adapt to changing climate and context. In this sense, the building envelope act as the first and most important boundary for adapt to the surrounding conditions, such as protection from natural climate hazards and connection to surrounding physical context. This research will focus on how to develop a building envelope that can be exposed in both different climate and context conditions meanwhile providing necessary living functions.

How can Adaptable (building) Envelope be situated in different environments?

Definition of adaptation
- the action or process of adapting or being adapted
- Biology the process of change by which an organism or species becomes better suited to its environment

Definition of envelope
- a covering or containing structure or layer

Definition of environment
- the surroundings or conditions in which a person, animal, or plant lives or operates
- the setting or conditions in which a particular activity is carried on
- the natural world, as a whole or in a particular geographical area, especially as affected by human activity
Biomimicry is a new science that studies nature’s models and then emulates these forms, process, systems, and strategies to solve human problems...

Janine Benyus  
co-founder & institute board president of Biomimicry 3.8  
birologist  
innovation consultant  
author

Biomimicry is selected as the research tool for this project. According to our own historical events, humans always bases on the objects’ idea that found in nature as inspiration to create tools in order to improve their daily life. The research of Biomimicry can help provide different hints and knowledge to develop the idea of Adaptability.

The research will focus on how the integumentary system of the warm-blooded vertebrates (mammals and birds) adapt to different environments. Conclusion will be drawn in the end as the conceptual statement and guidance for the envelope design of "Living Machine".

**Building envelope** act as the first and most important boundary to adapt surrounding condition

Skin is one of the most important parts of the body because it interfaces with the environment and is the first line of defence from external factors
Based on the biological classification system (5 kingdom classification system) on organisms. Animals has been classified as the organism which.................animals are generally being further classified into 2 major categories, vertebrates and invertebrates. Within the class of vertebrate, animals has been grouped into 5 different group including mammals, birds, fish, reptiles and amphibians based on their living behaviour. Two groups of animals out of five has an distinct character of internal self temperature regulation system, which are mammal and birds. They were known as "warm-blooded" vertebrates.

The research will focus on the level of organs and system. How organs works together to perform several functions as a system.

Many multi-cell organisms consist of several organ systems, which coordinate to allow for life

This pattern continues to a higher level with several organs functioning as an organ system to allow for reproduction, digestion, etc.

Several types of tissue work together in the form of an organ to produce a particular function

A group of such cells is a tissue, and in animals these occur as four basic types, namely epithelium, nervous tissue, muscle tissue, and connective tissue

All organisms consist of monomeric units called cells; some contain a single cell (unicellular) and others contain many units (multicellular)
The integumentary system is the physiological system that acts as the final packaging of the body which enshrouds all the other organs, including the muscle and skeletal structure. This system comprises of the skin and all other appendages organs that grows upon it, including nails, hairs on mammals and feathers on birds.

The functions of “Integumentary System”
The integumentary system has an important job of protecting the body and acts as the body’s first line of defence against infection, temperature change, and other challenges to homeostasis. Functions include:

- Protect the body’s internal organs
- Protect against bacteria invasion
- Protect the body from dehydration
- Protect the body against sunburns by secreting melanin
- Maintain homeostasis of the body against abrupt changes in temperature
- Maintenance of the body form
- Help excrete waste materials through perspiration
- Act as a receptor for touch, pressure, pain, temperature
- Generate vitamin D through exposure to ultraviolet light
- Store water, fat, glucose, and vitamin D
- Formation of new cells to repair minor injuries
2.2 MAMMALS AND BIRD’S INTEGUMENTARY ORGANS

The organs that comprise the integumentary system are hair, fur, nails, claws, scales, feathers, etc. All organisms have a skin which is the outermost and basic covering that encloses all the internal structures and organs of the body, this depends on different species. There are additional unique organs, for example hairs on mammal.

**Fig. (18)**
Sectional diagram of integumentary structure
http://coolessay.org/pars_docs/tw_refs/172/171074/171074_html_m2547f012.jpg

**Skin**
The skin is the most important and largest organ of the body, it is a complex structure composed of many different tissue covers the entire body to protect the internal organs. It can be generally divided into three separate layers as follows:

**Epidermis** (outermost layer):
The outermost layer of the skin contains four separate layers of epithelial tissue. The outer most layer is the stratum corneum that is about 2 to 30 cells thick. These are keratinized and dead cells that make the skin waterproof. The second and third layer consists of the stratum granulosum and stratum lucidum, which contain cells that are not keratinised as yet. As these skin grows, the cells are pushed outward and come towards the surface. The last and the deepest layer of the epidermis is the stratum germinativum. These cells are active mitotically and have the ability to reproduce, as these cells are living, thus, making them the manufacturing center for growing skin. The basal layer of the epidermis are cells called melanocytes, which produce the pigment melanin, the main contributors to skin colour and filter out ultraviolet radiation from sunlight.

**Dermis** (middle layer):
The dermis lies immediately after the epidermis. The dermis consists of its own blood supply and thus contains many complex structures. The sweat glands are present in this layer that collect waters and waste products from the blood stream. This waste is excreted from the pores in the epidermis along with the water in form of sweat. The hair roots are also present in this layer that help in the growth of hair. When the hair reaches outside the epidermis, the cells are dead. The connective tissue made of collagen fibres are also found in the dermis that help give the skin elasticity and strength.

**Hyprodermis / Subcutaneous Layer** (bottom layer):
The last layer of the skin containing the adipose tissues, cushions the delicate organs beneath the skin. The body temperature is also maintained within this layer by insulating the body to the temperature fluctuations.
**Arrector Pili Muscles**

These are smooth muscle cells that extend from the hair follicle till the papillary layer of the dermis. These arrector pili muscles cause the hair to become erect and give the feeling of ‘goose bumps’. Hair can trap more warm air when they are erect. Hence, during extreme cold environment, these muscles contract leading to erect hair. Under conditions of high temperature, the arrector pili muscles relax so that the hair lie flat on the skin and thus aid in the escape of heat.

**Nails**

Nails, claws and horns are structures that are derived from the skin. The nail bed gives rise to nails, that is thickened to form a lunula. The moon shaped structure that you observe at the base of your nails is called the lunula. The function of nails is to help in grasping and holding things. The nails act as counter force and help increase the sensitivity of the fingertip. They also protect the fingertips and underlying tissues from damage.

**Sebaceous Glands and Nerves**

Sebaceous glands secrete the oil coating for the hair shaft. They secrete sebum (oil) into hair follicles that *keeps the skin moist and soft* and *acts as a barrier against foreign substances*. The complex network of the nerves present all over the skin helps send and receive important impulses to and from the brain, thus playing a vital role in sense of touch.

**Sweat Glands**

Sweat glands have an opening through the skin pores, and they help in excretion of water and electrolytes. Eccrine sweat glands are found all over the body whereas apocrine sweat glands are present in armpits and groin. Eccrine glands are involved in the cooling mechanism of thermoregulation whereas, apocrine glands are involved in the secretion of chemicals and pheromones.

**Blood Vessels**

The *blood vessels* of the dermis *provide nutrients to the skin* and *help regulate body temperature* by enlarge the blood vessels (dilate), allowing large amounts of blood to circulate near the skin surface, where the heat can be released. Also narrow the blood vessels (constrict) to retain body’s heat.

**Hair / Feather**

Hair, feathers, scales, etc. are all derived from the skin. In case of humans, the hair extends to the surface from the hair roots or hair bulbs present in the dermis. The functions of the hair include protection and sensation to touch. Hair is made up of dead, keratinized cells that are bound together with the extracellular proteins. Each hair is divided into hair shaft that is the superficial layer and the root that is in the dermis. Hair follicle is the structure that surrounds the hair root. The oil glands present around the hair follicles help keep the hair and the surrounding skin moist. It also acts as a protective organ involved in temperature regulation.

Text reference:
http://www.buzzle.com/articles/integumentary-system-functions.html
### 2.3 INTERACTION BETWEEN OTHER SYSTEMS

#### Example 01 - Protection against bacteria invasion
Although skin is the major organ belongs to integumentary system, it also acts as one of the first defence mechanisms in the immune system. As the skin consists tiny glands that secrete sweat and oil. Those glands are termed exocrine glands and are not like the glands of the endocrine system. While it may feel a bit slimy, those fluids decrease the pH on the surface of the skin and kill microorganisms. There are even enzymes in the sweat that can digest bacteria. This is one of the example on how integumentary system work with immune system to carry out protection against bacteria invasion.

#### Example 02 - Temperature regulation
Another example on the topic of temperature regulation, the integumentary system also works closely with the circulatory system and the surface capillaries through organism. Capillaries near the surface of the skin open when the body needs to cool off and close when vertebrates need to conserve heat. The important sense of touch which nervous system depends on neurons embedded in vertebrate skin to sense the outside world. The diagram below illustrated how different system interact with each other to carry out the temperature regulation action. A good example of system regulation of your body can be found in the regulation of body temperatures. If your body gets too cold, a series of actions are taken to warm your body. Sensors throughout your nervous system can recognize when the temperature drops and might trigger your muscular system to start shivering. The constant contractions of your muscles allow heat to be generated. Your nervous and endocrine systems may also contract the blood vessels of your circulatory system to keep blood in the core of your body and not the extremities (like fingers).

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**Homeostasis and temperature control**

![Diagram illustrating the interaction between integumentary system with other system to enhance sensation](http://buffonescience9.wikispaces.com/file/view/homeostasis.gif/255785786/597x533/homeostasis.gif)

In this example, it show the facts that different system co-operate as a whole in order to regulate the body temperature. The entire process can be understood as an "receiver -> processor -> reactor " process. To further this function in a real-time continuous system, the process loops continuously, " receiver -> processor -> reactor -> receiver -> ... ".

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**TEMPERATURE DROP \(\rightarrow\) Integumentary system \(\rightarrow\) Nervous system \(\rightarrow\) Muscular system \(\rightarrow\) SHIVERING**
PART C
Research Analysis

3.1 Summary on Warm-blooded Vertebrate’s Integumentary System’s Function
3.2 Protection
3.3 Insulation
3.4 Regulation
3.5 Sensation
3.1 SUMMARY OF INTEGUMENTARY SYSTEM FUNCTIONS

Although warm-blooded vertebrate’s integumentary system / skin serves many functions, according to the focus on adaption between envelope and environment in this research, we can conclude that the skin in both mammals and birds have several common properties and major functions.

FUNCTIONS
- important in maintaining homeostasis in the body in 4 main aspects:

1) Protection
   - Protect the body’s internal organs
   - Protect against bacteria invasion
   - Protect the body from dehydration
   - Protect the body against sunburns by secreting melanin

2) Insulation
   the skin served as an covering for preventing internal heat loss

3) Regulation
   - Maintain homeostasis of the body against abrupt changes in temperature
   - Maintenance of the body form
   - Store water, fat, glucose, and vitamin D

4) Sensation
   the skin contains abundant nerve endings and receptors to detect stimuli related to temperature, touch, pressure and pain
   - Act as a receptor for touch, pressure, pain, temperature

Relationship between integumentary system performance and architectural performance

Unlike Architecture, animals are living organisms composed by millions of living cells or tissues, architecture faced certain constraints or limitations on materials properties, for example the growth of cells and metabolism activities which involved Bio-chemical effects.

One of the alternative approaches can be explored would be applying building physics, building services system and mechanical principles to understand how architecture can improve the architectural adaptation. The following chapter is base on building physic to understand how animals’ intergumentary system carry out different functions (Protect, Insulation, Regulation and Sensation).
3.2 PROTECTION - Mammals

Physical abrasion
Organs involved: Skin - epidermis and subcutaneous fat
Method: Materials properties & Strength

underneath the skin as a shock absorber.

Prevent Bacteria Invasion
Organs involved: Skin - epidermis
Method: Materials strength

The outermost layer of epidermis is the stratum corneum that is about 2 to 30 cells thick. These are keratinized and dead cells that prevent entry of bacteria, protect against injuries and also protects against desiccation.

Dehydration
Organs involved: Skin - epidermis, sebaceous gland that secrete sebum
Method: Materials properties & Watering

an antiseptic substance as well as keeping the epidermis supple hence preventing it from drying.

Block UV Radiation
Organs involved: Malpighian layer which provides melanin
Method: Colouring as shading

a black pigment lie in the dermis layer that protects the skin and the body against ultra-violet rays.

Expression of envelope performance by means of building physics principle

Fig. (27) Translation diagram of vertebrate skin into building physics
Prevent Bacteria Invasion
Organs involved: Skin - epidermis
Method: Materials strength

The outermost layer of epidermis is the stratum corneum that is about 2 to 30 cells thick. These are keratinized and dead cells that prevent entry of bacteria, protect against injuries and also protect against desiccation.

Physical abrasion
Organs involved: Contour feather
Method: Materials properties & Strength

The stronger and ridged contour feathers shield birds from wind.

Dehydration
Organs involved: Contour feather
Method: Material strength & Form

Contour feathers form most of the surface of the bird, streamlining it for flight and often waterproofing it.

The tough material they are made from, beta-keratin is water and wear resistant.

The interlocking feather barbs and a special coating that is either oily or waxy create a shield that water runs off.

Block UV Radiation
Organs involved: Feather
Method: Coloring and Shading

Darker colored feather might also provide protection from the sun.
3.3 **INSULATION** - Mammals and Birds

**Organs involved:** Hyprodermis (subcutaneous fat underneath the skin)  
**Method:** Multi-layering & Material properties

The fat tissue acts as a barrier to reduce the rate of internal heat loss by means of material properties. Cells in this layer contain higher percentages of water molecules, fats, and other ingredients (e.g., glucose) compared to Dermis and Epidermis.

**Expression of envelope performance by means of building physics principle**

**MAMMALS**  
**Organ involved:** Hairs  
**Method:** Additional external insulation

Trap warm air close to the skin as an additional insulation layer to reduce heat loss.

**BIRDS**  
**Organ involved:** Down feathers  
**Method:** Additional external insulation

Trap pockets of air close to the bird’s body by the loose arrangement of down feathers to help keep warm.

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Fig. (28)  
Diagram demonstrates the insulation effect

Fig. (29)  
Diagram on how hair rise  
http://upload.wikimedia.org/wikipedia/commons/4/4b/Anatomy_and_physiology_of_animals_Hair_muscle.jpg

Fig. (30)  
Diagram of a down feather  
http://upload.wikimedia.org/wikipedia/commons/0/0c/Anatomy_and_physiology_of_animals_Down_feather.jpg
3.4 TEMPERATURE REGULATION
- Mammals

**Reduce Heat loss**

**Organs involved**: hair follicle at the surface  
**Method**: Increase warm air volume

When an animal is in a cold environment and needs to reduce heat loss the erector muscles contract causing the hair or feathers to rise up and increase the layer of insulating air trapped. Due to its poor conductivity, heat loss is reduced.

![Diagram on how hair rise](http://upload.wikimedia.org/wikipedia/commons/4/4b/Anatomy_and_physiology_of_animals_Hair_muscle.jpg)

**Enhance Heat Loss**

**Organs involved**: sweat glands  
**Method**: Maximize evaporation  
**Sweating**: Produces sweat that evaporates during hot condition

![Diagram of sweating](http://upload.wikimedia.org/wikipedia/commons/a/a3/Anatomy_and_physiology_of_animals_Increase_heat_loss_by_skin.jpg)

Expression of envelope performance by means of building physics principle

- Use recycle water on envelope surface to cool down interior temperature
- Outdoor: Surrounding air movement
- Rigid outer layer
- Space contain services
- Elastic insulation layer
- Interior Space
- **Birds**

## Reduce Heat Loss

**Organs involved:** Down feathers  
**Method:** Increase volume to capture warm air

**Fluffing:** Birds will fluff out their feathers to create air pockets for additional insulation in cold temperatures.

**Organs involved:** Entire integumentary organs  
**Method:** reduce conduction surface area

**Tucking:** Bird standing on one leg or crouched to cover both legs with its feathers to shield them from the cold. Birds can also tuck their bills into their shoulder feathers for protection.

![Reduce heat loss surface area](image)

## Maximize Heat Gain

**Organs involved:** Entire integumentary organs  
**Method:** Increase solar heat gain surface area, orientation

**Sunning:** On sunny winter days, many birds will take advantage of solar heat by turning their backs to the sun (therefore exposing the largest surface of their bodies to the heat) and raising their feathers slightly. This allows the sun to heat the skin and feathers more efficiently. Wings may also be drooped or spread while sunning, and the tail may be spread as well.

![Increase heat gain surface area](image)
3.5  **ENHANCE SENSATION**

### Heat and Pressure

The skin is an organ of sensation. The skin contains an extensive network of nerve cells that detect and relay changes in the environment. There are separate receptors for heat, cold, touch, and pain. The sensation mostly carry out the sensory nerve cells which located in the dermis, it usually linked with the external layer (mammal’s hair or bird’s feather).

**MAMMALS**

*Organs involved:*

- Sensory nerve cells associated with hair

*Method:*

Sensitive to environmental changes i.e. heat, touch, pressure etc. they enable the body to respond to them hence escaping adverse changes in the environment.

**BIRDS**

*Organs involved: Filoplumes (hair-like feathers with a few soft barbs near the tip)*

They are associated with contour feathers and sensory or decorative in function. Feathers do not have nerves, but they do stimulate nerves that surround where the feather attaches to the bird. Birds can adjust the position of their feathers and posture depending on the stimulation of the nerves.
PART D
Research Conclusion

4.1 Translation of Architectural Language based on research result
4.2 Architectural Application Case Studies
4.3 Technical Studies
4.1 TRANSLATION OF ARCHITECTURAL LANGUAGES

Massing Strategy - Change in surface area and volume

**Sliding**
- move smoothly along a surface while maintaining continuous contact with it:

Result: Increasing / decreasing surface area and volume  
Possible Advantages: increase internal space  
Inspired through: Birds behaviour on temperature regulation

![Fig. (37) Bird fluffing](http://www.rspb.org.uk/community/resized-image.ashx/__size/500x0/__key/communityserver-discussions-components-files/905/2570.IMG_5F00_2804.jpg)

**Lifting**
- move upwards; be raised:

Result: Reduce surface contact, relocation  
Possible Advantages: 
Inspired through: Birds behaviour of temperature regulation

![Fig. (38) Bird tucking](http://erie.wbu.com/download/49939?type=.jpg)
Interlocking
- engage with each other by overlapping or by the fitting together of projections and recesses

Result: Increase area of connected surface
Possible advantages: Detachable connection of surfaces movable component
Inspired through: Bird’s contour feather networks

Overlapping
- extended over so as to cover partly

Result: Increase in thickness, reduce surface area
Possible Advantage: Increase surface strength and insulation properties
Inspired through: Bird’s feather arrangement & Mammal’s Skin layering

Fig. (39) Vaned feather

Fig. (40) Vaned feather

Fig. (41) Human nails
http://classes.midlandstech.edu/carterp/Courses/bio210/chap05/Slide9.JPG
Building Mechanics of Surface

**Extension**
- a part that is added to something to enlarge or prolong it

Result: Increase / decrease surface area
Possible Advantages: sheltering, surface for solar heat gain
Inspired through: Bird sunning behaviour

![Birds sunning behaviour](http://farm5.static.flickr.com/4042/4550399927_294f0545f2.jpg)

**Folding**
- be able to be bent or rearranged into a flatter or more compact shape

Result: Increase / decrease surface area
Possible Advantages: sheltering, surface for solar heat gain
Inspired through: Bird sunning behaviour

![Drawings of bird wings folding motion](http://www.ornithopter.de/grafik/herzog/faltung_k.gif)

**Flipping**
- turn over or cause to turn over with a sudden quick movement

Result: Additional air movement barrier
Possible Advantages: Enhance Insulation, Protection, Ventilation
Inspired through: Mammal Hair Rising

![Diagram on how hair rise](http://upload.wikimedia.org/wikipedia/commons/4/4b/Anatomy_and_physiology_of_animals_Hair_muscle.jpg)
4.2 ARCHITECTURAL APPLICATION

By understanding the (physical, bio-chemical) principle of how animals deal with their environment and also by the help of technologies developments, contemporary architecture has developed a number of solutions in terms of different aspects, for example design concepts, building systems and materials strategies etc..

The following case studies were selected based on the result of design guideline formulated after the research on warm-blooded vertebrates’ integumentary system as reference projects. Most of the applications concerned are to prevent excessive solar heat gains and indoor temperature control.

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Architectural References

Case Study #01
Flare system, Berlin
by Staab Architects

Application Field : Solar Shading Screen, Interactive Facade

System Mechanism : Rotation

Benefits : Reduce heat gain from solar radiation

Description :
The FLARE is a modular system of a dynamic façades for any building or wall typology. It acts like a living skin that allows a building to “express, communicate and interact with its environment.” The Flare interface acts as a lateral line and receives data input from sensor systems inside and outside the building. The FLARE system consists of a number of tiltable metal flake bodies supported by individual controllable pneumatic cylinders. Due to its adaptable geometric pattern, it can be mounted on any building or wall surface. Application of solar panels could be incorporated onto the external skin. The interface could then control the panel’s movement to absorb the most solar energy. In current application the system acts as an interactive media. The system is controlled by a computer and can be applied to any type of surface animation. Each metal flake reflects the “bright sky or sunlight when in vertical standby position. When a flake is tilted downwards by a computer controlled pneumatic piston, its face is shaded from the sky light and appears as a dark pixel. By reflecting ambient or direct sunlight, the individual flakes of the FLARE system act like pixels formed by natural light.”

Image and text reference source :
SOM + SCI-Arc on CF:Responsive Kinetic Facade
Architectural References

Case Study #02
France, Paris, Institut du Monde Arabe (Arab World Institute) by architect Jean Nouvel

Application Field: Solar Shading Screen (Mashrabiya Shading System)

System Mechanism: Radiation and overlapping

Benefits: Reduce heat gain from solar radiation, mediates daylight and reduce glare

Description:
This a double facade system, the inner facade is to control the amount of daylight that enters into the building. The outer glass panels are primitive, purely providing an air and water tight barrier from the outside. It is comprised of 240 metal units with a symmetrical array of motor controlled diagrams or apertures that open and close every hour. The design was rooted in Islamic pattern (Mashrabiya) that found in everything from textiles to architecture. The opening and closing of these apertures allowed for filtering and controlling the magnitude of light.
Application Field : Solar Shading Screen

System Mechanism : Folding

Benefits : Reduce heat gain from solar radiation, mediates daylight and reduce glare

Description :
The CJ Research and Development Center unique responsive facade aims to control the amount of direct sunlight entering the interior by additional kinetic shading devices. The accordion folded window shading wraps all three towers to provide protection from solar glare. In key areas the shading folds maximize solar control using a custom designed retractable mechanism based on the simple umbrella mechanism. The perforated steel strips installed on scissor actuators which can be can open or close automatically to ensure proper natural lighting while reducing overheating. Each unit is set between floors in groups of three ribbons, allowing the windows to be fully covered or fully exposed. When the drip is opened, it acts like a canopy providing shading from overhead direct sunlight.
Architectural References

Case Study #04
UAE, Abu Dhabi,
Investment Council Headquarters
by Aedas Ltd. and Arup Groups

Application Field: Solar Shading Screen (Mashrabiya Shading System)

System Mechanism: Folding

Benefits: Reduce heat gain from solar radiation, mediates daylight and reduce glare, energy generation

Description:
The design concept (The Mashrabiya shading system) of these 25-storey twin office towers in the United Arab Emirates is based on a traditional Arabic shading lattice-work, finding a parametric description for the geometry of the actuated facade panels and simulating their operation in response to sun exposure and changing incidence angles during the different days of the year. The south facing roofs of each tower incorporate photo-voltaic cells. The cocoon-like buildings are based on a pre-rationalised geometric form, fine-tuned via parametric design tools to achieve optimal wall to floor area ratio. A solar-responsive dynamic shading screen further decreases solar gain. This ‘Mashrabiya’ acts as a secondary skin that mediates daylight and reduces glare. The system is driven by renewable energy derived from the photo voltaic panels.
Application Field: Solar Shading Screen, Thermal building control, natural ventilation

System Mechanism: Rotation

Benefits: Thermal control by enhance natural ventilation, energy generation

Description:
The main entrance and the side overlooking the expo site are characterized by a moving media façade. The basis for the development of the biomimetic façade was the analysis of natural movement principles found in the flora world. The use of glass fibre reinforced plastics (GRP), combine with high tensile strength with low bending stiffness, allowed large reversible elastic deformations and thus enabled a completely new interpretation of convertible structures. The working mechanism of the kinetic facade is based on applying a compressive stress at the upper and lower ends of each lamella by actuators which causes an elastic bending deformation of the segments in order to create openings on the façade.
The façade is adaptable both to necessary light conditions as well as to structural-physical conditions. on top of climatic effect, by operating a special pre-programmed choreography, the kinematic facade acts as a moving focal-point for visitors to the Expo.To transfer the choreography into a motion sequence of the lamellas, all 216 servo motors have to be activated and controlled by the coordinating control unit. Each actuator, a servomotor driving a ball screw spindle, is synchronized, whereupon sensors continuously check the lamella’s status and report appropriate data back to the server via a BUS-system. Upper and lower motors often work with opposite power requirements (driving - braking). Therefore generated energy can be fed back into the local system to save energy.
Architectural References

Case Study #06
Germany, Hamburg,
The Soft House
by Prof. Sheila Kennedy, MIT team

Application Field: Solar Shading Screen (Living soft envelope System)

System Mechanism: Reassembly, sliding

Benefits: Reduce heat gain from solar radiation, reduce glare, energy generation and natural ventilation

Description:
The soft house was under construction in summer 2012, it is a set of live/work row house units which offer a new model for low carbon construction and an ecologically responsive lifestyle that can be personalized to meet homeowner needs. The soft house demonstrates how domestic infrastructure can become ‘soft’ - engaging flexible living concepts, carbon neutral solid wood (brettstapel) construction, and wireless building controls with responsive and performative textiles which create the public identity of the architecture. through the conceptual reframing of ‘soft’ and ‘hard’ materials and the integration of architecture, mobile textiles and clean energy infrastructure the soft house transforms the German passivehaus typology, offering a much more flexible living experience.

Application Field: Solar Shading Screen

System Mechanism: Expansion & contraction

Benefits: Reduce heat gain from solar radiation, reduce glare

Description:
The Homeostatic Facade System consists of a mess of silvery squiggles - The special material can be open and close in response to heat, effectively regulating temperature throughout a building’s interior. The key element of the system is a dielectric elastomer that uses electricity to change shape. The electricity deforms the squiggles, expanding them when it’s hot and sunny and contracting them when it’s cold.

Image and text reference source:
**Architectural References**

**Case Study #08**
Design Stage
Climate Camouflage: (HPMS)
by Mr. Jason Vollen, CASE

**Application Field**: Solar shading screen, energy generation

**System Mechanism**: Rotation, expansion & contraction

**Benefits**: renewable energy generation

**Description**:
The concept was inspired by homeostasis in biology system. The system regulates the building’s climate by a series of automatically responding louvers according to sunlight. It is control by actuator system acting like artificial muscle with louvers that consist of a dielectric elastomer wrapped over a flexible polymer core. The systems requires no motor or additional system and it only required low power consumption. The expansion and contraction of the elastomer causes the flexible core to bend. Silver electrodes on both faces assist by reflecting and diffusing light, while distributing an electrical charge across the elastomer, encouraging it to deform.

Image and text reference source:
http://www.sparkawards.com/galleries/index.cfm?entry=4324
Architecture References

Case Study #09
Research Stage
Hex Sphere
by DO|SU Studio

Application Field : - - -

System Mechanism : Expansion & contraction

Benefits : - - -

Description :
The concept of this research is to apply thermobimetal together into a more comprehensive prototype. The implications for high-performance buildings are tremendous. It is part of "bottoms-up" approach, designing and building an expandable surface that opens and closes in the shape of a sphere as temperatures change.

Case Study #10
Research Stage
Glass Shutter panel system
by DO|SU Studio

Application Field : Solar Shading Screen

System Mechanism : Expansion & contraction

Benefits : Reduce solar heat gain

Description :
The research used individual pieces of temperature responsive metal pattern that can operate like an organic shutter system and sandwiched between two panes of glass as part of a double glazing system. When, the bimetal will curl and constrict light from passing according to the sunlight penetration through the exterior surface of glass and heats the interior cavity. Depending on the brightness of the day, the bimetal shutter system can be calibrated to completely black-out the interior space, if necessary. This panel system can help reduce heat gain, reduce the need for artificial air-conditioning, and conserve energy. Without the need for manual controls or power if it placed in the strong sun facing facade.

Image and text reference source : http://dosustudioarchitecture.blogspot.nl
4.3 **Technical Studies**  
- composite materials

*Transparency insulation material*  
*TWD -*

**Material Properties**  
Application Area:  
Facade / covering, Wall

Material type: plastic, PMMA polymethyl methacrylate

**Available Dimension**  
Width: 1000 mm  
Height (thickness): 40mm, 60mm, 100 mm, 200 mm  
Length: 1400 mm

Weight: 0.0299999993 g/cm³

**Benefits:**
High solar transmission for a maximum energy gain  
Excellent thermal insulation  
Storage of solar energy for the room heating  
Reducing the amount of required heating energy

![Fig. (45)](http://www.stylepark.com/db-images/cms/okalux/img/p251458_488_336-1.jpg)  
Okalux TWD PC Insulation
![Fig. (46)](http://www.stylepark.com/db-images/cms/okalux/img/p251458_488_336-4.jpg)  
Okalux TWD PC Insulation  
 ![Fig. (47)](http://www.energie.ch/energie/themen/bautechnik/twd/schematwd.jpg)  
Illustration of application example of TWD  
 ![Fig. (48)](http://www.energie.ch/energie/themen/bautechnik/twd/twd.jpg)  
Illustration of TWD

The new passive-solar facade

1. solar glass  
2. transparent insulation  
3. absorber  
4. Aluminium rahmen isolated  
5. sunscreen  
6. opaque wall
Fibre glass reinforced materials
GFRP - Glass Fiber Reinforced Polymer

Material Properties
Application Area:
Exterior and Interior, roof, facade, floor

Material type: plastic, PMMA polymethyl methacrylate

Available Dimension
Width: flexible
Height (thickness): flexible
Length: flexible

Weight: 0.0299999993 g/cm³

Benefits:
High Strength
Lightweight
Resists salt water, chemicals, and the environment
Able to mold complex shapes
Low maintenance

Fig. (49) GFRP material
http://www.itke.uni-stuttgart.de/img/background/default/forschung.jpg

Fig. (50) GFRP application example
http://www.itke.uni-stuttgart.de/img/bilder/86-GFK-Glas-Verbund.JPG

Fig. (51) Example of GFRP application as window
http://www.itke.uni-stuttgart.de/img/bilder/80-GFK_fassade.jpg

Fig. (52) Bending-active membrane structure
http://www.itke.uni-stuttgart.de/img/background/68-detail.jpg

Fig. (53) ICD/ITKE Research Pavilion 2012
http://www.itke.uni-stuttgart.de/img/bilder/1941-Pavillion%202012-3.jpg
- building mechanical system

**Actuator**

An actuator is a component that converts energy into motion. It can also be used to apply a force. Typical actuator is a mechanical device that takes energy (usually energy that is created by air, electricity or liquid) and converts it into different kind of motion. That motion can be in virtually any form, such as blocking, clamping or ejecting. Actuators typically are used in manufacturing or industrial applications and might be used in devices such as motors, pumps, switches and valves.

*Application Area : Movable joint and function as motion structure muscles*

**Different type of actuator :**

**Electromechanical actuator**

An electric motor consists of at least one moving and one fixed electromechanical element. The working principle is based on physical deflection caused by a current-carrying conductor in a magnetic field.

**Hydraulic and Pneumatic actuator**

This type of fluid-based actuator is characterised by high power output in relation to their size, but this system also requires great energy input and is relatively inefficient. The system working principle formed by a motorised pump that serves as an engine to build up pressure using blades, gears, screws or pistons.

**Micro-actuator**

This type of actuator are relatively small in scale, it only allow a few millimetres extension but can provide an extremely large actuating force.

*MOVE! Architecture in Motion - Dynamic Components and Elements*
Sensoring System
Sensoring system acts as a receiver/measuring device, which are able to gather numerous different kinds of data on both direct physical parameters (e.g. temperature) as well as indirect quantities (e.g. comfort levels). These can include air temperature, relative humidity, air quality, light intensity, etc. Connected to control components (e.g. buttons and switches for manual controls), it can further regulate surrounding conditions.

Application area: Building envelopes, facade systems

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Fig. (56)
Different type of measuring devices
images captured from
"MOVE! Architecture in Motion - Dynamic Components and Elements"

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Fig. (57)
Diagram of sensory system throw chat on regulation
images captured from
"MOVE! Architecture in Motion - Dynamic Components and Elements"

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Fig. (58)
Diagram of sensory system throw chat on regulation
images captured from
"MOVE! Architecture in Motion - Dynamic Components and Elements"
PART E
Design Stage Preparation

Design Site Analysis
  5.1 Design Location Selection
  5.2 Selected Sites’ Information
  5.3 Site Climates

Design Parameters
  6.1 User Scenario
  6.2 Design Scale
  6.3 Climatic parameters
5.1 DESIGN LOCATION

Potential design location can be set as any place on earth that are suitable for habitation. For a better demonstration on the adaptability in terms of climate and context. The site selection criteria will based on

1) Climatic zoning (Koppen climate classification system)
2) Site context
CLIMATIC ZONES - The Köppen climate classification

GROUP A: Tropical/mega-thermal climates

- **Characteristic**: Relatively constant from month to month at high temperatures
- **Temperature**: Tropical climates have constant high temperature of 18 °C or higher (at sea level and low elevations)

GROUP B: Dry (arid and semiarid) climates

- **Characteristic**: Low precipitation, high evaporation rates
- **Temperature**: These climates’ average annual temperature in 20 °C

GROUP C: Temperate/mesothermal climates

- **Characteristic**: Summer temperatures are warm to hot and winters are mild
- **Temperature**: These climates have an average temperature above 10 °C in their warmest months (April to September in northern hemisphere), and a coldest month average between −3 °C and 18 °C

GROUP D: Continental/microthermal climate

- **Characteristic**: Summer temperatures are warm and winters are cold
- **Temperature**: These climates have an average temperature above 10 °C in their warmest months, and a coldest month average below −3 °C

GROUP E: Polar climate

- **Characteristic**: Low temperatures and precipitation
- **Temperature**: These climates' average temperatures below 10 °C in all twelve months of the year

This system is widely used to classify climate based on
1. annual and monthly averages of temperature
2. annual and monthly averages of precipitation
5.2 GENERAL INFORMATION ON SITE SELECTION

In order to demonstrate the possibilities of the adaptable character of the “Living Machine” in terms of climate, at least 2 site locations in different climatic zones will be selected based on the Koppen climate classification system.

Site 1
Singapore, Singapore
Asia (South East)
South of Tropical cancer
Climate zone: Group A (af)
Latitude : 01° 22’N
Longitude : 103° 48’E

Site 2
Cartagena, Spain
Europe (South)
South of Arctic Circle
Climate zone: Group B (bsh)
Latitude : 37° 37’N
Longitude : 00° 48’W

Site 3
Hong Kong Special Administration Region, China
Continent: Asia (South East)
South of Tropical cancer
Climate zone: Group C (cwa)
Climate type: Temperate/mesothermal climates
Latitude : 22° 17’N
Longitude : 114° 08’E
Territory : 1,104 km²

Site 4
New York, United States of America
North America (North East)
South of Arctic Circle
Climate zone: Group D (dfb)
Latitude : 57° 47’N
Longitude : 04° 23’W

Site 5
Nuuk, Greenland
Continent: North America (North East)
South of Equator
Climate zone: Group E (et)
Climate type: Tundra climate
Latitude: 64° 11’N
Longitude : 51° 45’W
Territory: 690 km²
POTENTIAL SITE LOCATIONS

Location:
Causeway Bay Waterfront,
Wan Chai District, Hong Kong Island

Site Condition:
On the edge of urban fabric, flat site profile without any obstruction of High-rise buildings.

Location:
West Kowloon Waterfront,
Mong Kok District,
Kowloon Peninsula

Site Condition:
Flat site profile with landscaped park. Next to an iconic tower, ICC (2nd highest building in HKSAR).

Location:
Nuuk

Site Condition:
On the edge of southern east part of Nuuk. Rural context slope at the edge of mountain.
5.3 CLIMATIC DATA

Hong Kong SAR - Temperature, Humidity and Precipitation

Temperature
Annual temperature typically varies from 13°C to 33°C and is rarely below 10°C or above 34°C.

Humidity
The annual relative humidity typically ranges from 47% (comfortable) to 89% (very humid), rarely dropping below 30% (comfortable) and reaching as high as 95% (very humid).

The air is driest around December 1, at which time the relative humidity drops below 55% (mildly humid) three days out of four; it is most humid around June 19, exceeding 86% (very humid) three days out of four.

Precipitation
Precipitation is most likely around June 19, occurring in 65% of days. Precipitation is least likely around November 22, occurring in 18% of days.

The most common forms of precipitation are light rain, thunderstorms, and moderate rain.

Light rain is the most severe precipitation observed during 50% of those days with precipitation. It is most likely around March 15, when it is observed during 30% of all days.

Thunderstorms are the most severe precipitation observed during 21% of those days with precipitation. They are most likely around August 10, when it is observed during 24% of all days.

Moderate rain is the most severe precipitation observed during 19% of those days with precipitation. It is most likely around June 20, when it is observed during 15% of all days.
Nuuk - Temperature, Humidity and Precipitation

**Temperature**
The annual temperature typically varies from -11°C to 11°C and is rarely below -19°C or above 15°C.

**Humidity**
The annual relative humidity typically ranges from 59% (mildly humid) to 98% (very humid), rarely dropping below 37% (comfortable) and reaching as high as 100% (very humid).

**Precipitation**
Precipitation is most likely around February 12, occurring in 70% of days. Precipitation is least likely around July 10, occurring in 53% of days.

The most common forms of precipitation are moderate snow, light snow, and moderate rain.

Moderate snow is the most severe precipitation observed during 40% of those days with precipitation. It is most likely around February 13, when it is observed during 41% of all days.

Light snow is the most severe precipitation observed during 19% of those days with precipitation. It is most likely around March 24, when it is observed during 19% of all days.

Moderate rain is the most severe precipitation observed during 17% of those days with precipitation. It is most likely around August 10, when it is observed during 30% of all days.
### 6.2 Design Parameters

**Climatic information**

- **Fig. (71) Site temperature range diagram**
- **Fig. (71) Site humidity range diagram**

**Climatic Design parameters**

- **Insulation performance**
- **Natural ventilation**
- **Solar radiation absorption**
- **Natural lighting capture**
- **Indoor air pressure**
- **Relative indoor temperature**

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**Considerable range**

- **Zone within comfortable temperature range of interior space**
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