An Evolutionary Architecture:
Adapted, interactive, and effectively integrated design

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ABSTRACT: This paper presents exploration of the principles that nature uses in the design of bio-climatic expressions and suggests how those principles can help architects to develop a better understanding for creating climate-conscious architecture. Instead of trying to make a complete set of design guidelines within this field, objective was to find some common design principles. Observed design principles were categorized under the rubrics Adapted design, Interactive Design and Effectively Integrated Design.
Keywords: bio-climatic design, adaptive, interactive, integrated design, interstitium

INTRODUCTION
Architecture has taken various forms at different places over time depending upon various local constraints (e.g. aesthetic, economic, social, climatic, and regulatory) each of which lead to decision making at a particular stage in the design process. Unfortunately, designers are often reluctant in giving apt response to climate conditions. Part of the reason behind this is the lack of inspiration and ability on the part of designers to incorporate environmental control with other objectives of design. Nature is an immense source of knowledge that can be used to solve the problems in many fields.

BACKGROUND
During the past fifty years, in addition to Victor Olgyay [1], many scholars including Baruch Givoni [2], Edward Mazria [3] and Donald Watson [4]to name a few, contributed to the literature on Bio-climatic architecture. Further investigations were done at different levels including the contributions by Ian McHarg [5], William McDonough and Michael Braungart [6], Darcy Thompson [7], and Janine Benyus [8], with their work categorized under different rubrics such as Organic Design, Biomimicry, and Eco-friendly design. Admittedly, all of the above scholars and designers made a significant contribution to the field of architecture by putting forth different perspectives on how nature can enhance or add new dimensions to Architecture for a better built environment.

In a majority of the existing nature-inspired creations, the organism was seen as form giver, part of the ecological cycles, and/or sometimes as an expression that merges with its surroundings. However, the idea of extracting some common principles of bio-climatic design from organisms in nature, which can serve as general design guidelines for all architecture, has not yet attracted the attention of many scholars.

METHODOLOGY
The underlying premise of this paper is same as that of TRIZ (Theory of Inventive Problem Solving) [9]. Assuming that nature has already solved the problem at hand and we can study living creatures to find solution to problems in built environment, most familiar examples from nature were studied to explore (1) how creatures respond to recurring but intermittent climate conditions, (2) how they respond to the consistent conditions that prevail throughout the year. Applying this study analogically to architecture, the building responsive to prevailing climate condition was addressed as adapted one and an interactive building was the one that changes its behaviour according to fluctuating climatic conditions. The idea of effective integration points at various opportunities to incorporate relevant bio-climatic design strategies with other purposes such as aesthetics and function.

ENQUIRY INTO NATURE
From the fur coat of the Polar Bear to the heat-exchanger mechanism of blood circulation in Grey Whales [10], there are numerous techniques that suggest means to achieve responsiveness to climate. Heliotropic plants suggest a means to optimize the efficiency of solar panels, behaviors of an elephant shows us the

potential of conductive cooling, branching of blood vessels gives an example of an efficient ducting system, and a desert plant shows us the benefits of minimizing surface-to-volume-ratio in hot and dry climates. In fact, that there is no single organism in which we can't find evidences of acclimatization. However, in some cases, just a naked eye observation is enough to extract the information while in other cases a microscopic study of the cells and tissues of the organisms might be required. Understanding that there are myriads of models in nature from which we can learn, the emphasis here is on the characteristics that enable them to acclimatize, while giving few examples of the related organisms. Such characteristics can be categorized as structural, behavioral and physiological depending on whether the means of adaptation is a permanent structural quality, a behavioral response, or a metabolic adjustment respectively.

ADAPTED DESIGN

The term “Adapted” is being used specifically to address those features which do not reflect any change in their properties in an annual, seasonal or diurnal cycle of external conditions. In other words, it is being used to address only permanent features in nature's expression which respond to climate conditions. Various references to temporary adaptations are discussed in the next chapter under the rubric “Interactive Design”.

In the case of an Elephant, the flapping of its enormous ears, as a response to high temperature, is a combination of three adaptations. A behavioural change can be noticed in the rate at which an Elephant flaps its ears. Rate of blood circulation is increased as its body temperature goes above normal. As an example of structural adaptation, a large number of blood vessels can be seen on the skin of its ears to release excess heat. Like the patterns of blood vessels in an Elephant ear, there are many examples of permanent adaptations in nature from which we can develop an understanding for designing those building components which remain fixed in their structural properties throughout the year. Being fixed in nature, their structural properties do not interact with changes in climate conditions. However, their materiality, shape and position can be designed as suitable to prevalent climate conditions ensuring that they do not worsen interior environment for the remaining part of the year. This practice can be more beneficial for climatic zones which do not reflect great variation in climatic condition over the year or for regions where the climate reaches extremes in either winter or summer while being acceptable for the remaining part of the year.

ADAPTATION IN MATERIALITY

Along with its shape, the composition of the material of the building envelope defines the extent of various exchanges between inside spaces and outside environment. While designing a building we can use Nature's intelligence in deciding the materiality of the building components. For example, we can use light colored, reflective, and high thermal capacity materials for hotter regions and darker shades with heat absorbing surfaces in colder parts of the world.

The vernacular architecture in many parts of the world includes the consideration for materiality in accordance with climate conditions. Sandstone having a high thermal capacity is the common building material in Rajasthan, India. Having a time lag of 8-9 hours, sandstone walls and roofs protect the enclosed spaces from the heat during the day and keep it warmer during cold nights.

While designing a building we can identify those parts of the whole structure which most probably will be stationary over the lifespan of the structure. As shown in figure below, the structural columns and beams (or walls if they are load bearing), floor slabs and the roof, and foundations are fixed part of the structure.

Figure 1: Default Building (left) fixed columns, beams, foundations, and Slabs (middle and right)

The idea of adaptation in materiality gives us an opportunity to make these fixed elements suitable to their climate. As their shape and position is fixed, a designer should choose the material that has internal properties (such as thermal mass and conductivity) suitable to climate for most part of the year because he has the opportunity to change only the surface characteristics as the seasons change. This approach has an added benefit that having identified the fixed part of the structure; we now know that the remaining part of the structure can be designed to change both its internal and surface characteristics diurnally or seasonally as desired. With such an understanding we see three different levels of opportunities for making a climate-responsive structure. At the first level (a), we can make decisions regarding internal properties of stationary parts, at the second level (b) we can choose to change the surface properties of these parts, and at the third level (c) we are free to change internal as well as surface properties of the remaining (operable) part of the structure. We can divide the whole building structure according to these three opportunity levels as shown below.

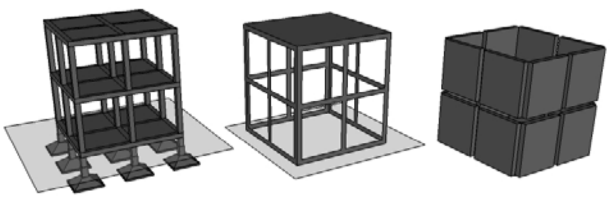

Figure 2: (a) Fixed structure, (b)Exposed surfaces of fixed structures, and (c)Interactive structure

However, depending on the climate conditions, a designer may prefer to have the same material properties for most of the structure throughout the year. In such cases the idea of Adapted materiality becomes more important.

ADAPTATION IN FORM

The principal form for any plant species can be defined as a system comprised of roots, stem, branches, leaves, fruit, and flowers. A climber can be compared to a tree not having the ability to stand on its week stem and hence taking support at various points on a surface. In principle, a beech tree is a climber that spreads inside the earth and develops more roots at several points to maintain the supply of water and nutrients. At an abstract level, the idea of adaptability in the principal form can be applied to design of the form of a building. The principal form of a building can be defined as a punctured shell with internal partitions supported by columns, beams, load bearing wall and the foundation placed at a specific depth with respect to earth surface. Depending on the climate type, it becomes important to decide whether to have a compact or dispersed form, a horizontal or vertical spread of mass, placement of occupied spaces on or underneath the earth surface, orientation of the building, size and number of openings, vegetation around the building, etc. Talking about adaptation as a practice known to ancient settlements, Ralph Knowles[11] argues that the location of the settlements was the first adaptation to the environment and the three components that define the location are orientation, juxtaposition and the general relation to the ground. Giving the example of Acoma pueblo, near Albuquerque, New Mexico, he asserts that the alignment of the building along with their exposure was based on direction of solar radiations. All buildings are oriented north-south to avoid heat gain in summer and take benefit of low altitude solar radiations in winter.

Figure 3: Plan of Acoma pueblo, near Albuquerque, New Mexico

INTERACTIVE DESIGN

Like the heliotropic and the phototropic species in nature that trace the movement of sun [12], our buildings should be intelligent enough to respond to external stimuli. Seasonal changes demand a different type of interactivity than daily changes because they go through only one cycle during the year. An appropriate response would be to design a building that also changes its daily behavior as the seasons change. However, such a response may result in extensive maintenance or automation costs. To make this approach more feasible, part of the building structure may be designed to change its characteristics once or twice a year to address seasonal changes while other part may respond to daily changes in the temperature, wind, light and humidity conditions. As shown in the figure below, all components on the external envelop which are not fixed and the exposed surfaces of fixed ones are the opportunities for incorporating the idea of interactivity to climate.

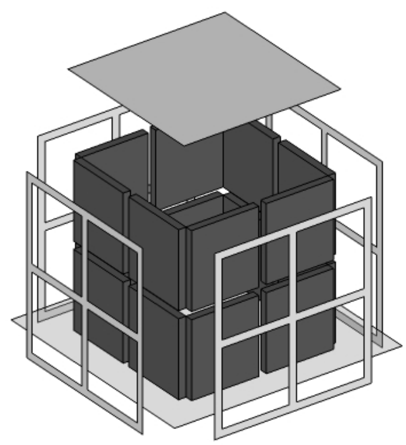

Figure 4: Zones for interactive design

In the zones shown above, we can further make decisions regarding the extent and type of operability. Similarly one can find such opportunities in the internal configuration of the building and design them to regulate various flows such as light and ventilation inside the building as desired. Once a designer identifies these opportunities, he can use nature as a measure of the design possibilities. For example, the lighter shade zone shown above which constitutes a major part of the building envelope, can be compared to the skin of an organism. This part of the building is directly exposed to external conditions and hence plays a primary role in the exchange of heat, light and air and water across the building structure.

INTERACTIVE MATERIALITY

If we understand the potential benefits of changing the material characteristics in our buildings periodically, we start looking at a building with different perspective.

For climates with extreme winters and summers, a building can be painted with darker color scheme for winters and lighter one for summer. Surfaces which are exposed to direct sun can be covered temporarily with a reflective material or covered with climbers during hotter part of the year to reduce heat gain through solar radiation.

On one hand we are limited to surface qualities of fixed components, but on the other hand we have unlimited options for designing the operable part of the structure. Ranging from surface qualities to intrinsic physical properties (such as thermal mass, density, and conductivity) of the material, and as well as form and position can be decided according to climatic changes. For example, operable panels can be colored twice a year with lighter and darker shade in summer and winter respectively, it can have removable layers to adjust its physical properties, and even a wall can be made of modular panels that can be changed seasonally, or the whole wall can be made of operable devices to regulate its behavior. Figures below show different expressions of the same structures as they change their behavior seasonally.

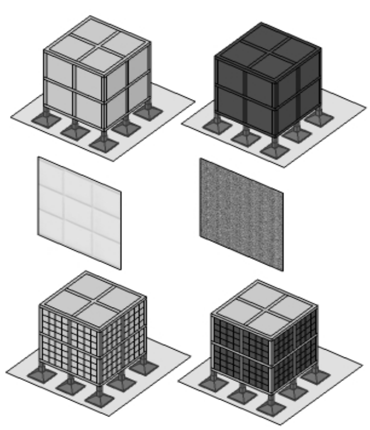

Figure5: Respective summer (left) and winter (right) expressions

OPENINGS

In addition to materiality and shape of the building envelope, we can define the behavior of openings to regulate the flows through the spaces inside the building. This is where the importance of operable attachments for the openings comes into play. As shown in figure below, for a fixed opening, an operable shading system can maintain its effectiveness as desired throughout the year.

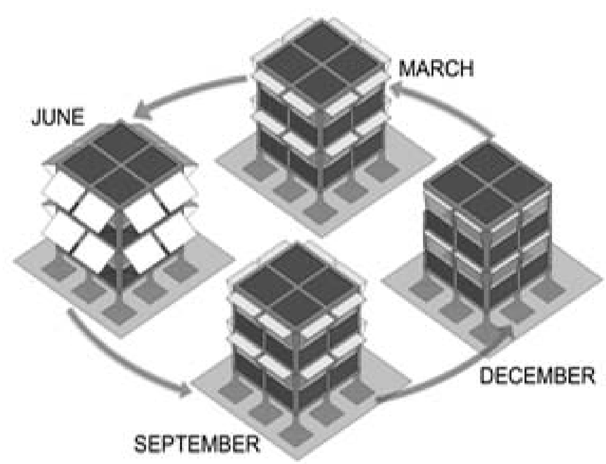

Figure 6: Positions of operable shading devices year round

INTERACTIVE FORM

Deciduous trees loose their leaves in winter to avoid water loss, and foliate again to start photosynthesis in spring; saguaro cactus widens its stem like an accordion to store water during the rainy season, and animals stretch their body in the sun to gain heat in winter or lay underground in a curled position to minimize heat loss from their body surface and seek shade to avoid sun in summer. However, the idea of making an interactive form is not common to our built environment.

Drawing analogies from Nature and Vernacular Architecture, Ralph Knowles and Pierre F Koenig[13,14,15] coined the concept of "Interstitium" which addresses the importance of interactivity in form. Interstitium is a term borrowed from "interstitial space" of human lungs. In his description of seasonal solar envelopes, he asserts that the conventional approach to solar access zoning emphasizes a fixed space time constraint on a building, whereas a solar envelope is actually kinetic. A winter solar envelope can be expanded to a bigger envelope in summer because shading is desirable to minimize heat gain from direct solar radiation.

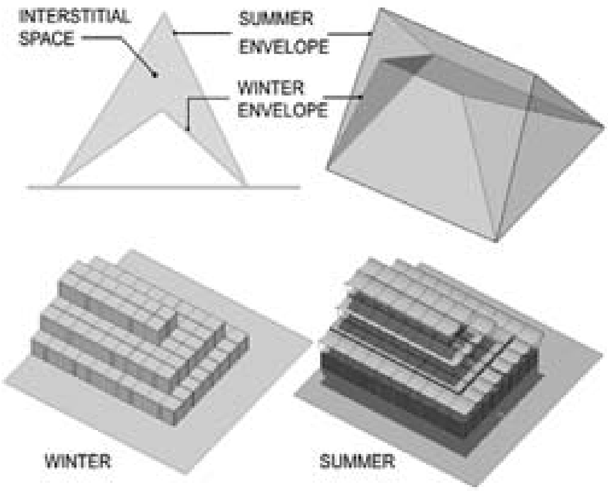

Figure 7: Interstitium, temporary addition of toldo.

OCCUPANCY PATTERN

Another lesson that nature teaches us is the benefits of migration. Many animal species migrate from one place to other seasonally. Some species of birds and animals migrate to far away places, while some species temporarily choose a different location close to their habitat.

BALANCING ADAPTIVE AND INTERACTIVE MATERIALITY

An ideal response to changing seasonal and diurnal conditions will demand that a building change its characteristics accordingly. A stimulus response comparable to heliotropes and phototropic species in nature seems to be impractical unless facilitated by intelligence of sensor devices which can track changes in outdoor conditions and guide the behaviour of a building. A practical approach to incorporate interactivity in the design of a building would be to decide on various intervals of time in a year and decide on the respective responses to climate. For example, we can decide on positions and shapes of a shading system for four seasons. Although, such a practice limits the effectiveness of the shading system, it tends to optimize the responsiveness of a building.

EFFECTIVELY INTEGRATED DESIGN

In addition to being a model from which we can learn, nature also serves as a measure for application of bio-climatic design strategies. While it shows us various possible options, it also tells us how we can combine these options to achieve our objective. To achieve the desired effect, the systems in nature use a combination of several techniques, each of which is applied to a certain extent so that the result is an optimized system. Nature tries to optimize the whole system instead of a component. Following three rubrics further elaborate in this idea.

MULTIDIMENSIONALITY OF THE SYSTEM

Nature uses several strategies depending upon the constraints and various functions that the design is expected to serve. As explained before, to make plants survive in the hot desert, nature has equipped them with various devices which differ from species to species. Also within the similar type of species (cacti), we can notice various differences in their stems, thorns, height branching etc. The Elephants found in Africa are notably different than those in Asia. The species of tortoise in Galapagos Islands vary according to respective ecological niches [16]. Although these are similar systems, nature has fine-tuned them according to their respective environment. A building along with its various components can be compared to the systems exhibited by nature. They also have various dimensions of surface properties, internal configuration, materiality etc. To achieve the same objective, we can elect to tweak one (or a set of) dimensions in one case and another (or a set of) different dimension in other case. Following figure shows multiple ways to avoid heat gain due to solar radiation.

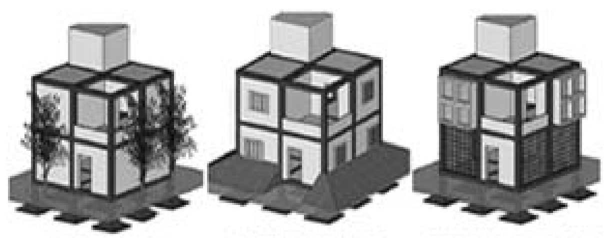

Figure 8: Multiple ways to avoid heat gain due to solar radiation

SCALE OF APPLICATION

There are different scales at which a concept of bioclimatic design is applied by nature. In some cases these concepts were integrated at the cellular level without making a significant contribution to the overall form, while in other cases their application became the prominent overall form. This idea opens up a whole new set of opportunities for designers to apply these concepts. Depending upon various constraints, they can decide to apply a technique to the scale of whole building, or they can decide to make a distributed application at a smaller scale. The figure below shows different scale of application for trapping solar radiation.

Figure 9: Trapping solar radiation with different scale of application

DUALITY OF PURPOSE

Nature uses minimum resources to make a construct; it is capable enough to do it in a way that it can solve multiple purposes. Like the stripes on the Zebra, that serves as thermoregulation and also helps with its camouflage against its predators. Applying this idea analogically in the design of a building, we can make conscious decisions in the use of resources and try to solve multiple purposes with a single construct. This understanding makes us capable to see a space or a mass having the ability to solve multiple functions and presents the opportunity to integrate concepts of bioclimatic design in any type of Architecture. It helps us see a space as an overlap of various individual spaces required for different functions.

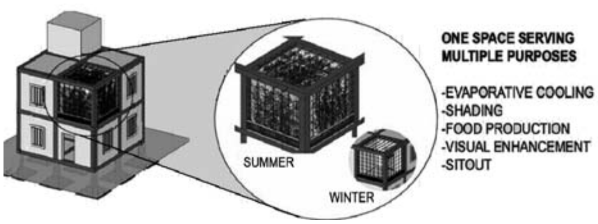

Figure 10: Multiple purpose served by a space

CONCLUSION

The three principles, namely 1) Adapted Design, 2) Interactive Design, and 3) Effectively Integrated Design, altogether provide a framework within which an architect can make decisions in designing a bio-climatic building. The ideas presented here are based on the study of limited examples and they are just a few of the many lessons that can be drawn from nature. The importance of this work, however, lies in that it identifies living creatures as models from which one can learn to devise strategic solutions to problems.

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