

# Body Patterning: A Model for Responsive and Interactive Building Envelope

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**Abstract.** Patterns in nature, either the cells forming the skins of living organisms or the sand forming the dunes, are in a constant change. Given that, pattern cannot only be seen as an absolute image of a whole formed by units, but it can also be seen as a process, which is controlled by stimuli affecting the outcome both visually and functionally in the architectural context. In this paper, the changes on the bodies of color and form changing living organisms are implemented to the building envelope as a dynamic process of adapting to the environment in terms of interaction. The bio-system is implemented to the envelope in terms of morphological, functional, and behavioral properties of particular living organisms. The proposed model is discussed in terms of adapting its environment by sensing and responding.

**Keywords:** Biomimicry, Pattern, Chromatophoric Architecture, Building Envelope.

## 1 Introduction

A long history of creating a recognizable order exists in design, which is called as pattern or occasionally ornament. These terms have been controversial so far, as Picon asserts that since Renaissance, architects have seen the ornamentation as an insignificant property than the organization of the whole building [1]. Besides, the exclusion of the pattern from the scene of the architecture had reached a peak with Modernism whose motto ‘form follows function’ made the pattern unnecessary within the built form. Since Alexander implies that production of building can be called as the assembly of patterns, the rejection of pattern from architecture has superseded by the idea that the pattern is a contributor to make architecture more profound [2]. However, regardless of these discussions in the architectural scene pattern as a formation appears from micro scale to macro scale as a transition between matter and energy in nature.

The very special type of the pattern formation occurs on the body of color and form changing organisms such as cephalopods as an adaptive process. This formation is called body patterning. The skin of these organisms works as an interface between

inner and outer body. The building envelope also works as an interface by enhancing the interaction of the building with its environment as well as providing the inner comfort. The building envelope is usually a static element, which cannot adapt the changing environment. Given that, the dynamic envelope that responds to stimuli has become a key issue to create an interactive and responsive skin.

This paper is about the implementation of dynamic body patterning of particular living organisms to the building envelope in terms of adaptation. The adaptation process is triggered by stimuli - sun, human movement, and visual changes in the environment. In Section 2, biologically inspired design will be explained as a methodology for this paper. In Section 3, the differentiation between pattern and ornament will be discussed by focusing on sensing and identity. Next, body patterning as a bio-system and man-made system will be examined. In Section 4, the changes on the bodies of particular living organisms are implemented to the building envelope as a dynamic process of adapting the environment in terms of camouflage (blending with its environment) and interaction. Finally, the outcomes will be discussed in terms of sensing and responding in the adaptive building envelope.

## **2 Biologically Inspired Design**

Nature has been an inspiration to solve problems, which is called as biomimicry. Biomimicry is defined as “the conscious emulation of life’s genius that is long tested by evolution” [3]. It is used as a method in several fields such as engineering and medicine and as well as architecture. However, when emulating the biological mechanisms to architecture, certain abstractions of natural mechanism should be needed from the early design process. Given that, the process can be defined as the biologically inspired design because of the analogical relation between natural and man-made systems.

Biologically inspired design (BID) has three properties such as adaptability, multi-ability, and evolvability [4]. In the proposed model, the focus is on adaptability of living organisms as a response to the ever-changing environment. The implementation of adaptation strategies of bio-systems occurs in several ways such as morphological, functional, and behavioral [5]. Morphological adaptation in nature is related to the appearance of the organism such as form and color. Functional and behavioral adaptations are defined as an organismic or systemic response to the stimuli [5]. However, functional adaptation is a chemical process such as CAM photosynthesis while behavioral adaptation is a physical such as concealment of cuttlefish.

The morphologic, functional, or behavioral properties are implemented from nature to the design by employing two different approaches, which are solution-driven, and problem-driven approaches. Searching other ecosystems or organisms for a defined problem is called problem-driven approach and analyzing specific ecosystems or organisms for adopting the found relations or behaviors into the design is called solution-driven approach [6]. The solution-driven approach is adopted in this paper in order to form the pattern based dynamic envelope, which adapts its environment by enhancing the inner comfort and interacting with its environment.

Regarding pattern in architecture, the inspiration of nature oscillates between imitated and functional morphology. Arslan and Gönenç Sorguç assert that the imitation of the organisms' form has usually been encountered in architecture as a kind of visual expression [7]. For example, the pattern of neural networks is repeated in façades of the different buildings in order to create a complex expression. Thus, detailed analysis of the morphology becomes a key issue in order to enhance the functionality of the building envelope as well as visibility of it.

### 3 Patterning and Ornamentation on Bodies

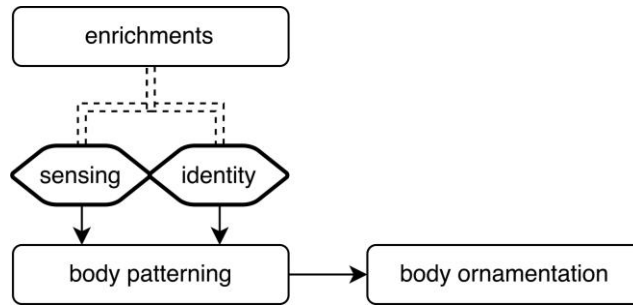
Pattern can be defined as the sequence or frequency emerging from the repetition of a unit. However, identical units are not necessary for being a pattern. For example, all the seashells have different lines on their outer surface, which cannot hamper to distinguish the seashells from other organisms. Several categorizations of pattern exist, but none of them captures the whole. Pickover suggests three categories that are the patterns of representing nature, mathematics and symmetry and human art by implying that any of the patterns can be tagged with another category than the suggested one [8]. In this paper, we define two main categories such as nature and man-made patterns by combining the mathematics with human art.

In nature, pattern formations can be categorized as bubbles, waves, bodies, branches, breakdowns, fluids, grains, communities etc. [9]. For example, the bubbles tend to make the minimum surface, while the living organisms try to adapt to their environments by forming their pattern of molecules or cells. Every single entity within a pattern creates a complex whole, which sometimes creates a visual appealing ornamentation, especially in the living organisms.

In man-made realm, there are several subcategories of pattern, which depend on the discipline. For architecture, Alexander defines three sub-categories that are the urban, building and construction, which can be used for creating a design pattern [2]. Some of the patterns represent topological relations between entities such as spatial patterns. Some of them work for the embellishment such as decorative patterns in order to create an appealing look. Moreover, decorative patterns such as Islamic patterns have aesthetic values additional to geometrical properties of units, which help to tile a surface or construct a 3D form like Muqarnas.

Pattern has certain mathematical relations of elements and functional properties, which define the organization of the whole, while ornament has aesthetic properties, which are not necessarily because of function. Moreover, pattern and ornament differ in terms of *symbolic meaning* [10]. Gleiniger asserts that the pattern theory is a rational phenomenon, and the ornament theory is a sensorial and meaningful phenomenon [10]. Rationality of pattern comes from the mechanism behind the outcome, the rules, or relations that form the final pattern. Sensory of ornament comes from the *enrichment* [11] of the pattern as an addition to the rationality of it. Enrichments appeal the senses with additional static or dynamic properties upon the organization of units (pattern). As it is shown in Fig.1, body ornamentation can be defined as the enrichments of sensing and identity upon body patterning. *Meaning* in

Gleiniger's explanation of symbolism is replaced with identity due to properties of body ornamentation in nature [10]. Body ornamentation ensures sensing the environment and responding to it as well as giving identity to the organism.



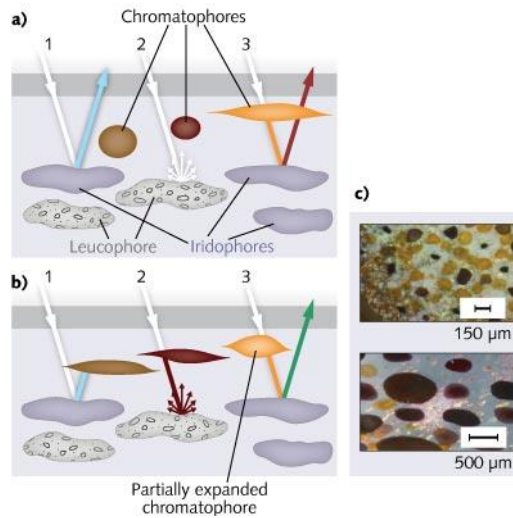
**Fig. 1.** The relation between body patterning and ornamentation

By re-examining the nature, regarding pattern alternation on bodies of living organisms has shown body patterning occurs both functionally and visually. Moreover, body ornamentation usually occurs especially in birds for attracting mates, which is an example of *extended phenotype* [12] addition to the morphogenetic pattern formation of birds. According to Dawkins, phenotype is not confined to biological processes within the body and extended to embody all effects that a gene has on its environment [12]. Thus, both in animals and humans have the extended phenotype regarding body ornamentation as an extension to their own skin. The body patterning is analyzed in two sections as bio-system and man-made system.

### 3.1 Body Patterning as a Bio-System

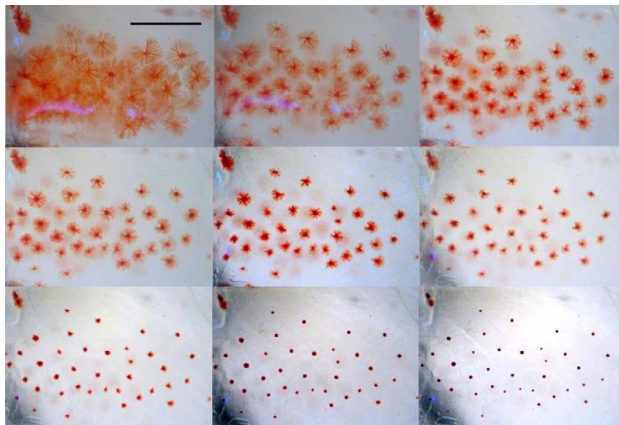
As a pattern formation's sub-category, the very special kind of pattern changes occurs on the skin of animals, which have the ability to change the form and the color of their skin. Body patterning is mainly related to the communication between living organisms as well as adaptation to environmental changes. Moreover, their interactive skin gives an identity to the organism. For example, cephalopods, which have sophisticated skin adaptation system in both color and form adapt perfectly to the environment thanks to its multi-layered skin. According to Packard, the body pattern of cephalopods is comprised of the chromatophores, reflecting cells and skin muscles [13]. The most prominent element of body patterns are chromatophores cells due to their colors and they appear on the specific region of the body [14]. The chromatophores vary in color and filter the light to define the color of skin by inflating and deflating, which is shown in Fig. 2. If the chromatophores inflate, they color the skin to their own colors by filtering the reflected light. If they deflate, the light, which comes through the skin, is reflected as white color by reaching leucophore cells. Iridophores produce iridescent colors. These pigment-like cells work as muscles and ensure two functions such as *concealment and communication* [14].

By inflating and deflating, they block each other and create several patterns on the body of the organism.



**Fig. 2.** The layered system of the chromatophores of *Cephalopod* [15]

Another example for the pattern formation on bodies is the skin of Antarctic krill. The skin has several muscle-like pigments, which can inflate and deflate in order to change the color and overall pattern of the skin (Fig. 3).



**Fig. 3.** The mechanism of Antarctic Krill's skin [16]

### 3.2 Body Patterning as a Man-made System

Unlike other organisms, human does not have peculiar body patterning to attract the attention or simply protect himself from climatic changes. Thus, people in tribes

cover their skin with ornaments to emphasize their position among others, sometimes for rituals and conceal themselves for protection. Ornaments might be applied on body in order to transfer social messages in a community as an example of the interaction. They show the already gained social status or act as an interface for the communication of given social identities [17]. These ornaments generally consist of geometrical elements repeated all over the body. They have symbolic meaning as ornament and they follow a geometric rationality as pattern. The symbolic meanings of the body ornaments are comprised of idealized representations of persons of different ages, gender specific representations [17], group affiliations, marital status, social standings, or levels of wealth etc. [18]. Like in nature, ornamental enrichments upon repeated units occur in body patterning on human bodies. This early version of body ornamentation is followed by fashion design that is out of the scope of this paper.

Body patterning can be translated to the building envelope as an order of units in the context of architecture. The organization of units in a pattern is defined by the rhythm of the elements. This rhythm can be classified as regular and irregular regarding whether the grasping the period of the pattern or not. Both of them can be used to tile a surface or strengthen linear materials such as rope by weaving. Unlike the static organization of units, the dynamic organization is used to control inner comfort or animate the data.

## **4 A Model For Bio-Inspired Interactive and Responsive Building Envelope Based On Pattern**

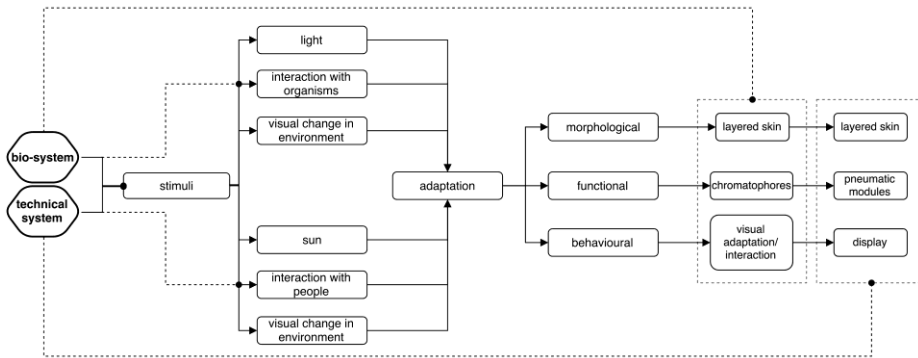
The environment of the building visually changes due to the rapid urban development in recent years. On the other hand, we live in a digital world, many information passes through visual displays. Thus, building skin should have the ability to both blend and interact with its surroundings by becoming an interface or media façade. When we search for such interfaces in nature, we see that several organisms such as chameleon and cuttlefish have adaptable skins. By employing the methodology of biologically inspired design mentioned above, the proposed model transfers the functional morphology of the cuttlefish's skin as well as the behavior of it in terms of responding stimuli. Changing patterns on the body of living organisms, which are utilized as both the concealment and accentuation elements, is implemented to the building façade, envelope, or installation.

### **4.1 The Implementation of Pattern Formation of Skins**

Living organisms adapt to their environments according to stimuli. Their skin adaptation systems are affected especially by light, interaction with other organisms and visual changes in the environment. These stimuli are transferred to the proposed model as parameters, which affect the overall formation of the building envelope.

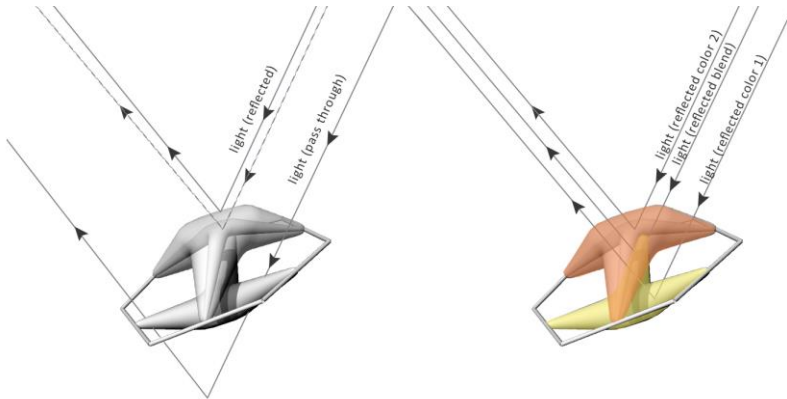
The pattern formations of skins are implemented according to three parameters of evolution and adaptation of living organisms such as morphological, functional, and

behavioral [5]. Morphological bio-system is transferred as layered skin, which behaves as a display by using pneumatic modules instead of muscle-like chromatophores. The stimuli, which affect the bio-skin, are light, interaction with living organisms and visual changes in the environment. These stimuli are implemented as the sun, interaction with people and visual change in the environment, respectively. While keeping the light and visual change stimuli the same, the interaction between organisms is transferred as human interaction within the space due to its habitability as a building envelope (Fig. 4).



**Fig. 4.** The implementation diagram of proposed system

By implementing the properties of particular organisms' skin, an interactive pixelated building envelope is proposed by using double-layer of pneumatic units, which generated from a hexagonal grid. A unit is generated by selecting the medians of the hexagon. For the first layer, mediums of the 1, 3, 5 edges are selected and for the second layer vice versa. These selected edges form the one pneumatic module of the system as an implementation of chromatophores of the skin of color-form changing organisms (Fig. 5). The pneumatic units control the light by inflating and deflating as well as responding visually to the environmental changes and human movement by using LED, which is placed within each module.

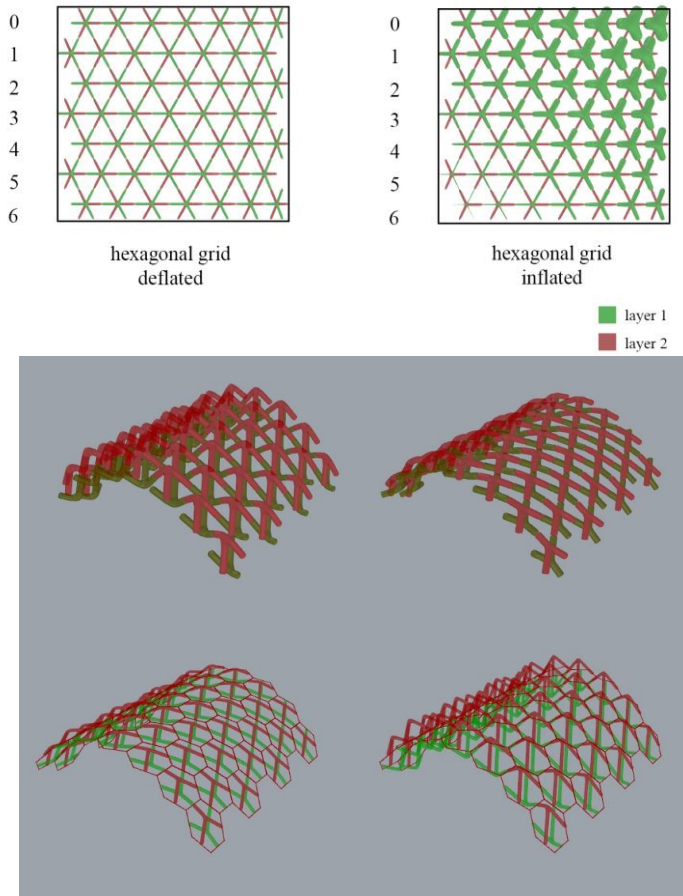


**Fig. 5.** The behavior of the double-layered modules in terms of light transmission.

Modules can be activated separately by being affected by different stimuli. Modules create a pattern when they form the envelope, façade, or installation upon a regular grid. The building envelope application of the system is mainly discussed in the paper.

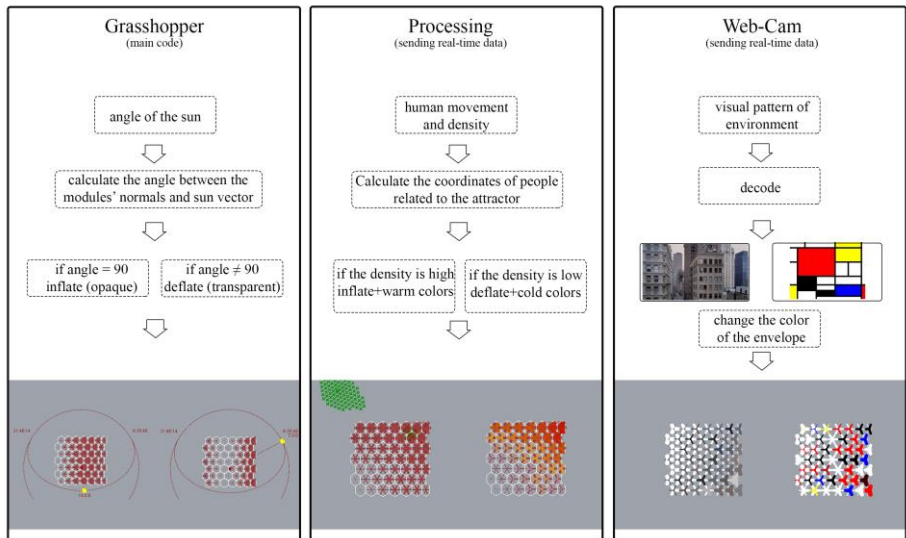
#### **4.2 The Pattern-based Responsive and Interactive Envelope**

To generate the model, double-layer hexagonal grid, which is called hexagonal honeycomb is chosen to place the modules (Fig. 6). These two layers are interwoven and have the ability to change in color and form by using pneumatic, and LED systems like in the chromatophore cells of cephalopods. Several protrusions can be achieved by changing the distance parameter between layers as it is shown in Fig. 6.



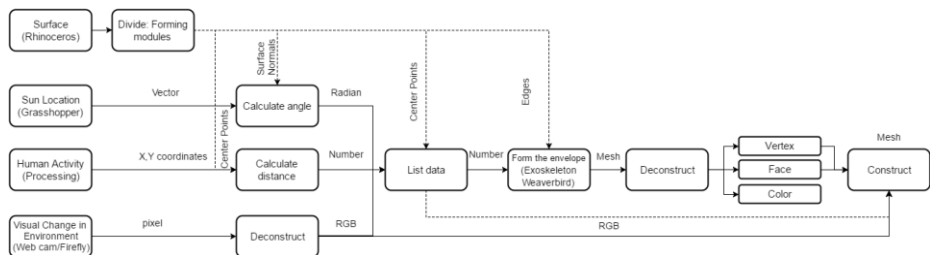
**Fig. 6.** The double-layer grid system, which is derived from hexagonal grid

The envelope responds to the sun, human movement, and visual changes in the environment. Pneumatic cells control the light transmission in the envelope according to the sun vector. Cells are inflated to protect the interior of the envelope from the direct sunlight. Thus, the seasons and the location of the envelope directly affect it. Moreover, the human movement within the envelope affects the body patterning by reflecting warm or cold colors according to the location and density of people. If the density of people increases in particular area, the modules reflect warm colors at that area, vice versa. The visual change in the environment also affects the envelope's formation and color by decoding pixel information of real-time data (Fig. 7).



**Fig. 7.** The diagram, which shows the algorithm of the model

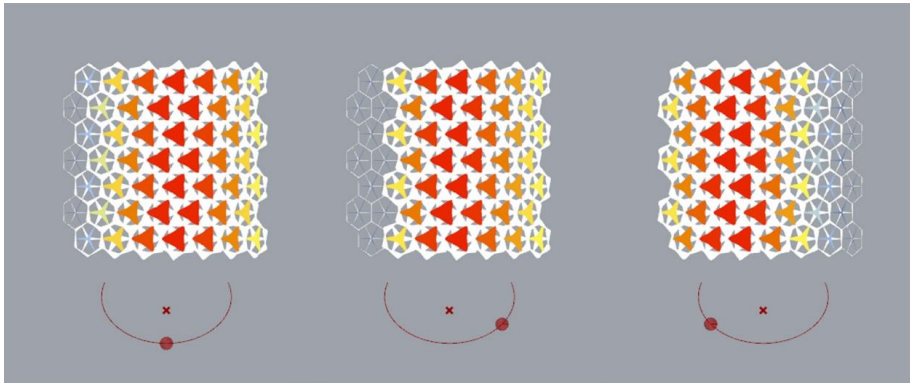
Data transmission between mediums is shown in Fig. 8. Any surface, which is created in or imported to Rhinoceros, can be used as an initial form. The initial form can be 2D or 3D surface. Next, the sun, human movement and visual change in the environment are represented in Grasshopper as vector, X and Y coordinates, and pixel, respectively. The angle between sun vector and surface normal is used for controlling the light transmission and heat. Moreover, the distance between the coordinates of the people and envelope is employed to control the inflation and deflation integrated with color as a signaling system. Human movement is transferred from Processing. Visual data of the environment is gathered from Webcam. Pixel data, which is collected via Webcam, affects the color matrix of LED system.



**Fig. 8.** The data transmission between mediums

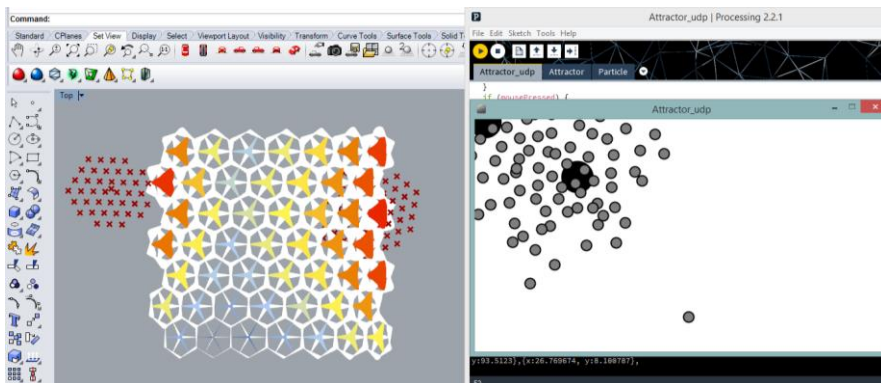
Sun vector, which depends on the location, the date and time affect the envelope by triggering the inflation, if the sun angle is close to the 90° and deflation if the angle is not close to 90° (Fig. 9). The light transmission is hampered by inflation and allowed by deflation. Moreover, color changes can be integrated with the inflation-deflation

system. For example, bright colors can be used in hot climates in order to increase reflection and reduce heat gain.



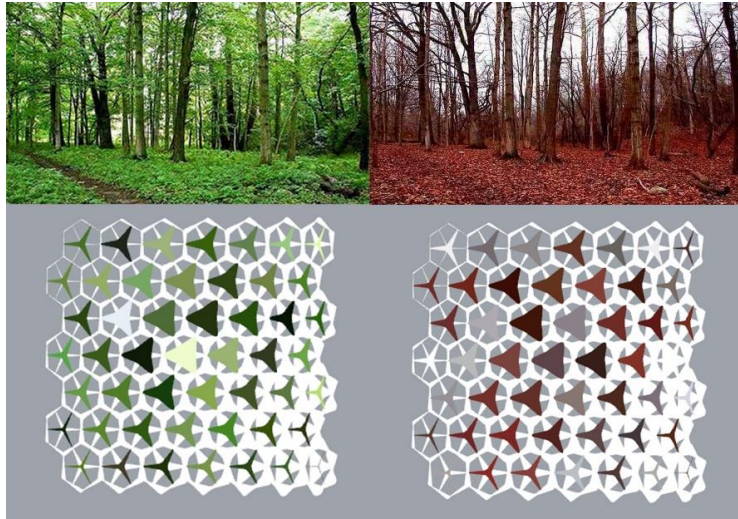
**Fig. 9.** The body patterning of the envelope according to the position of sun

Human movement and density within the envelope is represented in Processing with particles, which follow the attraction points by adapting the code for this model [19]. The user can control the location and number of attraction points. The changes of information are directly transferred to Grasshopper via ports (Fig. 10). The red points in Rhinoceros represent the number and location of people, which interact with the envelope. Points are synchronized with the Processing.



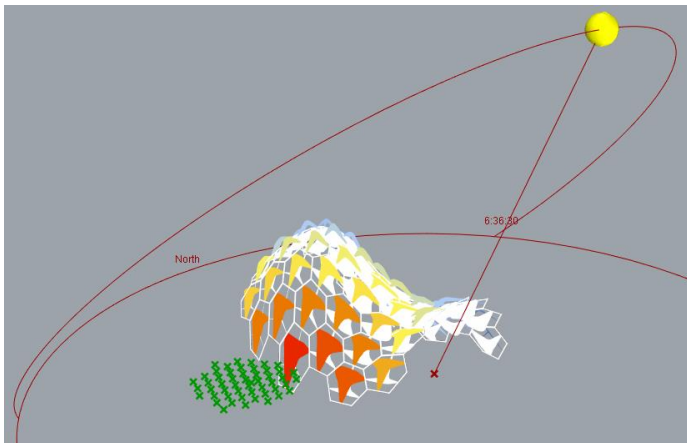
**Fig. 10.** The body patterning of the envelope according to the human movement

Visual changes in the environment are captured via Webcam. Firefly add-on in Grasshopper is used in order to transfer the captured image's RGB values to the model. Seasons as well as silhouette related changes in the environment directly affect the overall look of the envelope (Fig. 11).



**Fig. 11.** The body patterning of the envelope according to visual changes in the environment

Combinations of the three stimuli – the sun, human movement, and environmental changes create many possibilities in terms of interior space and exterior appearance of the interactive and responsive envelope (Fig. 12).



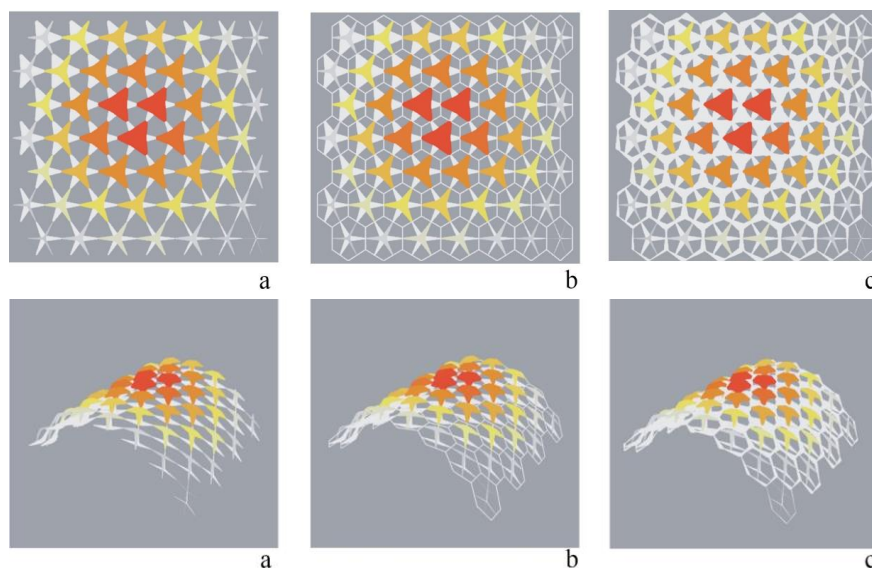
**Fig. 12.** The combination of stimuli affecting the envelope

### 4.3 The Outputs of the Model and Potentials

The model can be used to generate building envelope, façade, or installation from macro to micro scale in design. Pneumatic modules can be produced by using PVC, which is activated by air pressure. After producing the modules, they are replaced

upon a hexagonal grid to form the envelope. Arduino can control the actuation with the light and movement sensors. The visual pattern of the environment and human movement can be used for the pneumatic actuation. The data, which is read as pixels, affects the inflation/deflation process by controlling air pressure with Solenoid valves within Arduino.

Three different application of model as a building envelope is shown in Fig. 13. In Fig. 13a, the pneumatic modules, which act like a textile, can be used with scaffolds due to stability. In Fig. 13b, the pneumatic modules are attached to a hexagonal structure with joints. In Fig. 13c, the whole system is produced as a pneumatic textile with PVC materials, which can take shape of a proposed form. Constant air should be provided to this type of system in order to take its shape and be stable. Changes within the envelope create the different kind of spaces affecting the senses.



**Fig. 13.** The variations of the building envelope produced with the model

The façade application of the model can ensure the heat and light optimization in new buildings as well as old ones. Moreover, it can be used as a permanent or temporary display on building façades. Old buildings can visually blend with the environment thanks to the pigmented system. In micro scale, the model can be used as a kinetic installation in a space by employing the human interaction of the model. The model can be modified in the interior application for optimizing sound absorption or reflection in terms of performance.

Variations of the model are shown in Table 1. The type of stimuli and relation to the bottom or top layer of pneumatic grid affect the overall body patterning as well as the function of the skin such as the envelope, façade, or installation.











































## 5 Discussion and Results

The body patterning mechanism of color and form changing organisms is adapted to the proposed model in terms of morphological, functional, and behavioral properties of the organisms by employing BID (Biologically Inspired Design) approach. Body patterning is defined as the rational organization of units, while body ornamentation with color and form changes is defined as the enrichments on the repetitive structure by sensing the stimuli and ensuring the identity of the envelope. The enrichments can be seen as *extended phenotype* [12], which ensures adaptation of the organism to its environment.

The variations are obtained owing to the sun, human interaction, and visual change in the environment. The sun orientation of the model yields to sustainable architecture with heat gain and light optimization. The optimization of the light and heat gain will be analyzed in the future research. The human interaction provides a dynamic relationship with the inhabitants of the building while defining a surface of communication with its environment. Moreover, the human and environmental interactions create *data animation* [20] on the building envelope regarding *chromatophoric architecture* [20], which is defined as a 3D grid of pixels. The use of color as an animation of social data shows how groups of people come together and behave [20]. However, further research is needed for analyzing the movement patterns of people interacting with the envelope. Thanks to the color adaptation of the model; it blends with its surroundings. Combinations of these agents can create microclimates in the interior of the pattern-based envelope by expressing the senses of inhabitants, which is transformed to the color data. This also works as a signaling system as in nature, which can be defined as media façade in terms of architecture.

Understanding the adaptations of living organisms leads to defining the building envelope as an expression, negotiation, and performance entity aside from dividing interior and exterior. Thus, the building envelope is not seen a static element and is seen as a system which can be transformed according to several stimuli like in nature. The building envelope becomes a responsive and interactive skin, which adapts changes in the environment with the pneumatic and pigmented system. Further research is necessary for the production of the pneumatic system and interaction circuits to test whether the proposed model works as expected. Given that, the model is a part of an ongoing research in terms of the production of the proposed system.

**Table 1:** The variations of proposed model.

Model	Stimuli			Body Patterning							
	Sun	Human Activity	Visual Pattern	Plan 1		Perspective		Plan 2	Perspective	Façade	Installation (Amorph Surface)
0 Usage				Building Envelope (Architectural Textile)				Building Envelope (Structural)		Textile	Building Envelope (Structural)
1	Bottom Layer	+	-	-							
	Top Layer	+	-	-	07.2015 07.00			12.2015 10.00			
2	Bottom Layer	+	-	+							
	Top Layer	+	-	+	07.2015 14.00			12.2015 14.00			
3	Bottom Layer	+	-	+							
	Top Layer	+	-	+	07.2015 20.00			12.2015 18.00			
4	Bottom Layer	-	+	-			one structure				
	Top Layer	-	+	-							
5	Bottom Layer	-	+	-			one structure				
	Top Layer	-	+	+							
6	Bottom Layer	+	-	-							
	Top Layer	-	+	+	double structure		one structure				
7	Bottom Layer	+	-	-			double structure				
	Top Layer	-	+	+	07.2015 14.00			07.2015 14.00			

## References

1. Picon, A.: Ornament: The Politics of Architecture and Subjectivity, Wiley (2013)
2. Alexander, C., Ishikawa, S., & Silverstein, M.: A Pattern Language: Towns, Buildings, Construction, New York: Oxford University Press (1977)
3. Benyus, J.M.: Biomimicry: Innovation Inspired by Nature, pp. 2. HarperCollins: New York. (1997)
4. Loonen, R. C. G. M.: Bio-inspired Adaptive Building Skins. Biotechnologies and Biomimetics for Civil Engineering, pp 115-134 (2014)
5. Azcón-Bieto, J. and Talón, M.: Fundamentos de fisiología vegetal. Barcelona: McGraw-Hill Interamericana (2000), Retrieved from López, M., Ramón R. and Martínez, S.: How plants inspire façades. From plants to architecture: Biomimetic principles for the development of adaptive architectural envelopes. Renewable and Sustainable Energy Reviews Volume 67, January 2017, pp. 692–703 (2017)
6. Vattam, S., Helms, M. and Goel, A. K.: Biologically Inspired Innovation in Engineering Design: A Cognitive Study. Technical Report GIT-GVU-07-07, Graphics, Visualization and Usability Center, Georgia Institute of Technology (2007)
7. Arslan S. and Gönenç Sorguç A.: Exploring Complex Forms in Nature through Mathematical Modeling: A Case of Turritella Terebra, eCAADe 2009, pp. 665-672 (2009)
8. Pickover, C. A.: The Pattern Book: Fractals, Art, and Nature. World Scientific Publishing Co. Pte. Ltd. (1995)

9. Ball, P.: *The Self-Made Tapestry: Pattern Formation in Nature*. Oxford University Press (1999)
10. Gleiniger, A.: *New Patterns? Old Patterns?—On The Emotional Appeal Of Ornament. Pattern: ornament, structure, and behavior*. Eds. Gleiniger, A. and Vrachliotis, G., pp. 13-25 (2009)
11. Norberg-Schulz, C.: “Architektuornament,” in: *Ornament ohne Ornament? (Ornament without ornament?)*, publ. by Mark Buchmann, exhibition catalog in 5 brochures, Zurich (no. 5), pp. 24–29 (1965). Retrieved from Gleiniger, A.: *New Patterns? Old Patterns?—On The Emotional Appeal Of Ornament. Pattern: ornament, structure, and behavior*. Eds. Andrea Gleiniger and Georg Vrachliotis pp. 13-25 (2009)
12. Dawkins, R.: *The Extended Phenotype*. Oxford: Oxford University Press (1982)
13. Packard, A. and Sanders, G. D.: *Body patterns of Octopus vulgaris and maturation of the response to disturbance*. *Animal Behaviour* 19, 780-790 (1971)
14. Messenger, J.B.: *Cephalopod chromatophores: neurobiology and natural history*. *Biol. Rev.*, 76, pp. 473-528 (2001)
15. URL-1 <<http://www.laserfocusworld.com/content/dam/lfw/print-articles/2012/12/1212LFWnews02web.jpg>> (September 19, 2015).
16. URL-2 <<http://mdiazbiol4550.blogspot.com.tr/2010/11/release-of-rpch-from-neurosecretory.html>>, (September 19, 2015).
17. Joyce, R. A.: *Archaeology of the Body*. *Annual Review of Anthropology*, Vol. 34, pp. 139-158 (2005)
18. Kuhn, S. L. and Stiner, M. C.: *Body Ornamentation as Information Technology: Towards an Understanding of the Significance of Early Beads, Rethinking the Human Revolution: New Behavioural and Biological Perspectives on the Origin and Dispersal of Modern Humans*. McDonald Institute for Archaeological Research University of Cambridge (2007)
19. URL-4 <<http://natureofcode.com/book/preface/#520-attraction-and-repulsion-behaviors>> (May 18, 2015).
20. Maddox, A. and Haeusler, M.: *Social Form. Chromatophoric architecture: Designing for 3D media façades*. Berlin: Jovis (2010)