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Gradient Transparency: Marine Animals As a Source of Inspiration.

Exploring Material Bio-Mimicry through the Latest 3D Printing Technology in Architectural surfaces.

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Digital fabrication technologies are changing rapidly the way we design, as any other tool would affect the way we produce space. Multi layered 3D printing is already allowing architects, designers and engineers to experiment with new design processes and new ways of production. At the same time, little research has being done in the way gradient transparency (through multiple layered surfaces) can affect the design process through computation; a field that deserves further investigation. The focus of this paper is to explore bio-inspired material finding design processes while combining biology, architecture and material science.We explore performance driven design possibilities through a study of marine animals -and specifically cephalopods- where opacity between skin layers is controlled through color pigments - while black pigments are called melanophores - which is often used as a type of camouflage. We propose a computation model that follows the logic of gradient transparency through pigments to fit complex "host surfaces". We define a "host" surface as a basic geometry on which the pigments are computed. This study provides the methodology for the design of biomimetic surfaces with gradient transparency, using controlled and computated sub geometries analogous to the melanophores pigments. We finally propose Pigment Skin, a computational design model as an example to materialize this study.

Keywords: *Gradient transparency, multilayering, marine animals, biomimicry, computation, pigments, 3d printing,*

1. Introduction

Gradient transparency in nature is evident in a range of animals including amphibians, reptiles, fish and cephalopods like squid. This is achieved through the translocation of color pigments called melanophores, which are responsible for generating skin and eye color for many cold blooded animals. Historic documentation and analysis of such biological functions is already evident from the ancient times, when Aristotle wrote about adaptive coloration in the way the octopus can tune its color. Biologically inspired engineering extends from Chemistry and Physics to Genetics and Mechanical / Electrical engineering. It is an effort to design new, man-made systems, based on biological models. These innovative systems are might often use the same principles to solve different scale functions and constraints. Adaptive coloration and selective concealment are now part of an emerging field of research in science, with both theoretical and technological challenges, with a number of diverse examples. At the same time, 3d printing is also an emerging field where designers and engineers experiment with new design processes and new ways of production. Already examples from the MIT Mediated matter group such as the "Imaginary Beings" or the 3d printed experiments at the ACADIA 2014 conference demonstrate examples where objects with multi layered materials are digitally designed and fabricated (see figure 1) .

Figure 1
figure 1: Imaginary Beings (Neri Oxman) (top) and 3d printed chair (Zaha Hadid architects) (bottom)

At the same time, little research has being done in the way gradient transparency (through multiple layered surfaces) can affect the design process through computation; a field that deserves further investigation.This paper is part of a practice based PhD research in computational design and CAM for small scale architectural installations. Gradient Transparency is a work in process project that is split in two phases; the first phase explores biomimicry of marine animals and computation. During this phase, we explored the design rules that define the functional frame of melanophores, from local scales (within a single cell) to global scales (the emerging patterns and zones withing the whole body of a marine animal). These rules where then incorporated in a computation model where pigments can be applied to complicated surfaces. As an applied example, we introduced Squid Skin, a synthetic computation system where we can tune performance of pigments, through aggregation, scale and pattern.The second phase we will test the fundamental exchange between the mathematical realm -in the form of digital modeling of gradient transparency (multilayered) surfaces- and the material realm - in the form of material prototype fabrication and manufacturing. Multi opacity 3d printing of Pigment Skin will also be examined. This paper focuses on the first phase.

2. Method

2.1 Microscopic examination. Marine animals can change their skin color to approximately mimic the hue of their immediate environment, but also as a response to temperature, mood, stress levels and social cues. Cephalopoda such as squid use chemical cells and light reflecting cells to sense the environment they are in and change their skin color. This is achieved though colored pigments translocation in light reflecting cells called chromatophores. This process, known as physiological colour change, is most widely studied in melanophores, since melanin is the darkest and most visible pigment. In most species with a relatively thin dermis, the dermal melanophores tend to be flat and cover a large surface area (see figure 2).

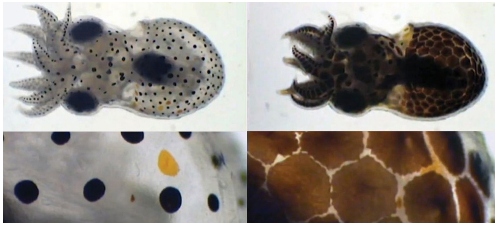

Figure 2
Low magnification and close-up photographs of a hatchling blue-ringed octopus (Hapalochlaena lunulata), (Roy Caldwell)

Flat dermal melanophores often overlay other chromatophores, so when the pigment is dispersed throughout the cell the skin appears dark. When the pigment is aggregated toward the centre of the cell, the pigments in other chromatophores are exposed to light and the skin takes on their hue. On the dispersion of melanin, the light is no longer scattered and the skin appears dark (see figure 3).

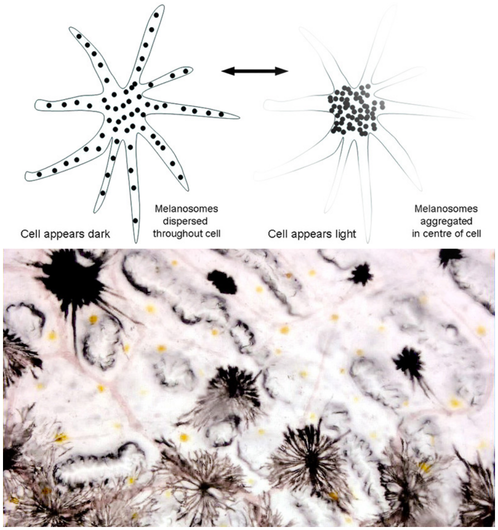

Figure 3
Melanophores with dispersed or aggregated melanosomes (Chiswick Chap) (top) and Melanophores responding to Adrenaline (Zephyris)

2.2 Morphological / emerging pattern analysis. Geometric analysis based on scale and shape served as the basis for the computational model; emerging patterns and zones appear on marine animals across their body and shape.

2.3 Computational modeling. Using the Rhino 3D software and plugins such as Grasshopper and Lunchbox, the melanophore cells - pigment logic is translated into clusters of pixels in different zones in the computational model.

3. Result

3.1 Biological epidermis design rules. The geometric design rules in Cephalopods melanophore skin are analyzed along three levels of detail: local, regional and global. These different scales are in correlation with each other, allowing for full body coverage through a surface along the Cephalopod body. We chose to examine the epidermis through three different scales in order to be able to clarify and translate the design rules into a computational model.

3.1.1 Local. The local level of organization relates to single melanophore cell, its anatomy and its geometry. All melanophore cells are similar in Cephalopods such as the Bigfeen rif squid (Sepioteuthis lessoniana). Cephalopod melanophores all function similarly, compacting from as small as a tenth of a millimetre to 2 mm in diameter (20 : 1 expansion factor) [5] The time that it takes to go from fully retracted to fully expanded varies and is based on the organism, but recent work has reported it to be typically around 300 ms [6].Melanophore cells contain black or brown pigments.

3.1.2 Regional. The regional level of organization describes the interconnection of chromatofores on the Cephalopod skin and the correlation between local shape variation and regional functionality of the system. As mentioned before, melanophores can change, due to physiological and/or environmental conditions, creating different categories of clusters (see figure 4).

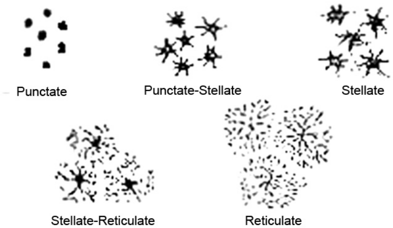

Figure 4
Regional level organization between Melanophores

These clusters vary from punctate to punctate-stellate to stellate to stellate- reticulate to reticulate (branched) and vice versa.

3.1.3 Global. The global level of organization relates to the long-range distribution of the pigments across the body of the Cephalopod. Emerging darker areas appear on its body depending on the external stimuli and environment, creating radial, linear and full cover patterns. (see figure 5).

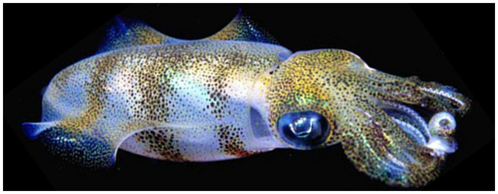

Figure 5
Bigfin reef squid (Rokus Groenfeld)

3.2 Pigment skin: gradient transparency computation model. The gradient transparency computational model incorporates the organism-specific design principles to a host surface with new functional specifications. Pigment skin allows for neighborhood relationships between large numbers of parametrically and digitally controlled surfaces and polysurfaces (which we will call "pigments") that are applied on a digitally designed surface. The pigments are manipulated in a way to meet specific topological requirements. In order to implement an understandable (and in phase two, a 3d printable) example, we applied the pigments on a digital surface that would act as a hat, providing both privacy and shade for the user.

Pigment skin is designed to meet privacy and shading requirements at three organizational levels following the geometric rules on the three different scales already examined: (i) local definition of a standard unit (pigment) and design of different unit geometries according to their neighbors (ii) regional / zone application of patterns that follow specific paths and promote gradient transparency of the hosting surface through their change of size, and (iii) global manipulation of the host polysurface that affect local adaptation of pigment geometries.

3.2.1 Local. The local level of organization treats the standard scale unit (the pigment) as a building block by taking into account the geometry and size of its neighbors, which can also be smaller or larger, in order to reveal or conceal areas behind the host surface (see figure 6).

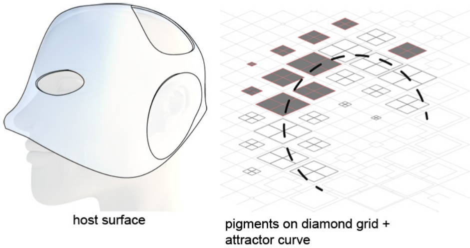

Figure 6
Host surface and diamond shaped pigments

All pigments will be 3d printed, so there is no need to limit the number of different pigment sizes. The largest pigment is 6mm X 6mm and has a height of 2mm.The parametric model we designed allows implementing different grids on the host surface. In this specific study, we used a diamond shaped grid, due to its reference to structure and possible future use in structural surfaces In order to create gradient transparency based on pigments sizes, they are locally scaled with the use of an attractor curve.

3.2.2 Regional and Global. The regional and global level of organization orients pigments along specific paths / zones on the host surface defined by attractor curves in the parametric model. The curves around the eyes and ears where used as attractors in the parametric model, causing aggregations of pigments on their periphery (see figure 7).

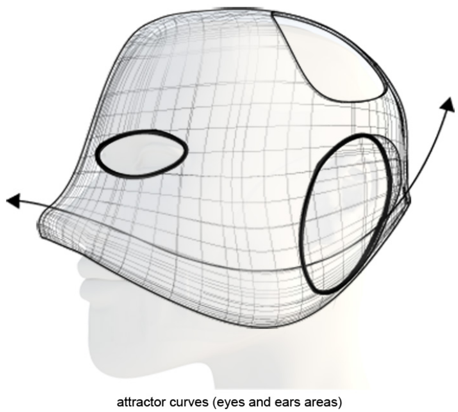

Figure 7
Attractor curves in the eyes and ears areas

The eyes area and ears areas are treated in analogy with the Punctate Melanophore clusters (Area with high pigment aggregation) and the ears area is analogous to the Reticulate (Branching) Melanophore clusters that are already mentioned (see figure 5). Applying the diamond pigments on the host surface and scaling them according to their distance to the attractor curves creates the gradient transparency effect. Manipulating the parametric model allows for different transparencies as well as different percentages of pigments or grid (see figure 8).

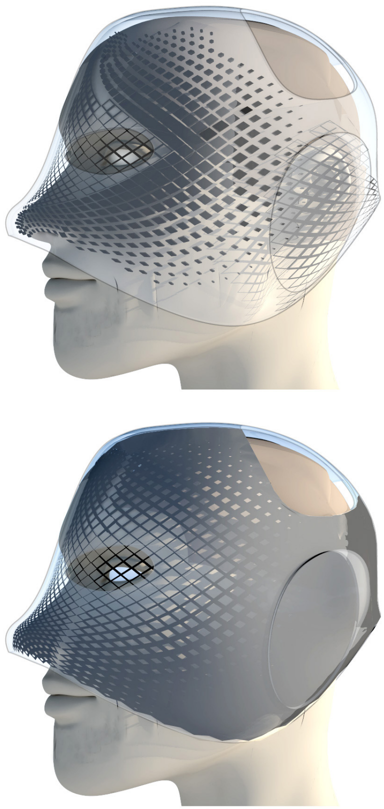

Figure 8
Computer renderings of different grades of transparency

Another parameter of the Pigment skin com-

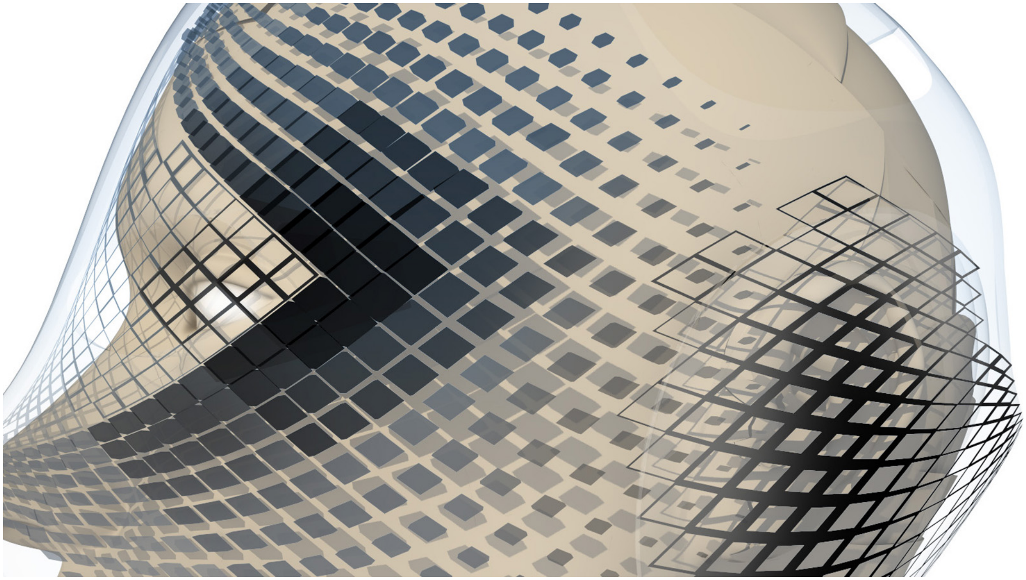

Figure 9
Gradient transparency of both host surface and pigments

putational model allows for different transparencies of the pigments themselves, in analogy to Melanophore cells in Cephalopods (see figure 9).

4. Discussion and further development

The Gradient Transparency study is a generative computational design project based on the design principles found in the biological skins of marine animals and specifically Cephalopods. It aims to address a digital design problem that has barely any references in current architectural design through the use of Parametric Component Population. PCP has become a common method to adapt discreet geometrical components to complex surfaces and shapes. The host surface is modeled as a NURBS surface subdivided in to u and v directions, on which the geometric components (here the pigments) are populated and manipulated through main attractor curves.

Future development will focus on the multi layered 3d printing of the Pigment Skin surface. We will use latest multi-jet modeling technologies of the Projet 5000 by 3DSystems for fabricating the host surface and pigments. Study models will be 3d printed of PLA clear plastic (host surface) and which will embed PLA black plastic (pigments).

The originality of this study lies in its combination of experimental analytical methods such as microscopic examination and advanced computational geometry techniques. The outcome, a functional bio-inspired system is based on interdisciplinary research between biology, materials technology and architecture.

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REFERENCES

Borrelli, L., Gherardi, F. and Fiorito, G. 2006, *A catalogue of body patterning in Cephalopoda*, Firenze University Press, Florence

Deleuze, G. 1994, *Difference and repetition*, Columbia University Press, New York

Lipson, H. and Melba, K. 2013, *Fabricated: the new world of 3D printing*, Wiley, Indianapolis

Nixon, M. 2003, *The brains and lifes of Cephalopods*, OUP, Oxford

Oxman, N. 2011, 'Variable property rapid prototyping', in Da Silva, P.J. and Chua, C.K. (eds) 2011, *Virtual and Physical Prototyping*, Taylor & Francis, London, pp. 3-31

Pawlyn, M, 2011, *Biomimicry in Architecture*, RIBA, London

Qiming, W., Gossweiler, G., Craig, S. and Zhao, X. 2014, 'Cephalopod-inspired design of electro-mechano-chemically responsive elastomers for on-demand fluorescent patterning', *Nature communications 5*, 4899