Bioshading System Design Methodology - PoC 1.0

Maria João de Oliveira[1], Vasco Moreira Rato[2], Carla Leitão[3]

[1] *Instituto Universitário de Lisboa (ISCTE-IUL), DINÂMIA'CET, Lisboa, Portugal,* [2]*Instituto Universitário de Lisboa (ISCTE-IUL), ISTAR, Lisboa, Portugal,* [3]*Rensselaer Polytechnic Institute, Troy, NY*

[1]*https://ciencia.iscte-iul.pt/authors/maria-joao-de-oliveira/cv,*[2]*https://ciencia.iscte-iul.pt/authors/vasco-rato/cv,* [3] *http://aum.aumstudio.org/*

[1] *mjoao.oliveira@iscte-iul.pt,* [2]*vasco.rato@iscte-iul.pt,* [3]*leitac@rpi.edu*

Abstract. Nature provides a remarkable database of possible adaptation strategies that can be implemented in biomimetic design of shading systems. However, at this moment, successful design methods are conditioned to a limited knowledge and ability to emulate nature's strategies to meet corresponding functional needs. The implementation of biomimetic processes has as some major challenges: 1- the search and selection among several databases of appropriate strategies adopted by nature; 2- difficulties in reading, interpreting and translating at different scales; 3- connection problems between concepts and material premises. The selection of nature models is a very common situation among architectural projects. Form, structures, motion, processes, morphologies and systems are available mimicking strategies, that could be implemented at different scales, contexts, materials, elements among others.

Keywords. Biomimetics; Nature based-design; Methodology; Plants; Biohading-systems.

01 Naturalizing Architecture Design

The presented research investigation aims to present a Bioshading System Design Methodology (BSDM), based on a problem-based approach. Starting with the architectural challenge of design, solutions will be sought in nature to solve specific Bioshading-systems performative requirements. The hypothesis that sustain the methodology development lies over an informed process that integrates and interrelates three domain areas: 1- Architecture; 2- Nature; and 3- Artifact.

In this context, Architecture domain roots its basis on the formation of the process, computational environmental analysis and diagnosis. This formation process is conducted through environmental analysis softwares integrated through parametric design tools. Nature domain is defined through an abstraction process. Sustained by a plant mapping adaptation processes table, the creation of a *meme's* semantics should trigger a performance-based design process. Performance-based design is achieved when computational analysis and digital simulation are integrated with the exploration of shape and structure through generative design processes. The artifact domain is the physical materialization of the design concept that enables its evaluation and emulation. Performance-based design processes and digital fabrication tools are integrated components, supporting the creation of the artifact. It is aimed that the presented methodology could be used by both, academics and professionals of architecture. In this perspective the methodology will be supported by a digital toolkit. The idea is that the toolkit allows a greater proximity between the students and the process, working as a pedagogical vehicle of information, promoting debate between working groups and facilitating the development and organization of the different tasks to be carried out during the process. Therefore, in order to elaborate and validate the final methodology and its toolkit components, a real time proof of concept was conducted.

02 Proof of Concept (PoC) 1.0

PoC 1.0 was conducted through two separate four-hours sessions. Ten voluntary participants, students and professionals of the architecture field, organized in pairs, carried out this experience. None of the participants had knowledge or base experience in the field of biomimetics. To this purpose, a computer laboratory was used.

The main goal for this experience was that participants could develop a shading system to a pre-determined building and defined context, using the BSDM, PoC 1.0 sessions aimed to test and evaluate the methodology considering three criteria: 1- Methodology Clarity (evaluated by the participants at the end of the experience); 2- PoC 1.0 sessions (participants were invited to evaluate i) the clarity of the methodology oral presentation and supplied digital material, ii) time of session and iii) the available means); and finally 3- Method Operability and its Outputs (evaluation performed by the team instructors and developers of the methodology, over each developed project, about their method clarity and applicability, goal definitions, biomimetic meme path matrix generation, design solutions and its technical implementation).

Bioshading System Design Methodology relies on a circular order of nine phases, equally distributed by three domains: *Architecture*, *Nature* and *Artifact* (Figure 1). Initiating its journey with the Architectural domain, the created and applied methodology has a problem-based concept design approach. The first session guided the participants through the *Architecture* and *Nature* domain phases, in order to, respectively, define the shading system goals and to create its concept design *Biomeme*. The Goals definition consisted on defining the main functions of the future designed shading system, as well as the actions that will support them and the agents that will enable it. The *Biomeme* consists on the creation of a fictional *meme*[1], that is a product of the studied vascular plants events combined with the aimed functions of the shading system. The second session was essentially focused in the Generation and Simulation phases of the *Artifact* domain, and it was strongly devoted to the digital design project, considering types of structure, actuation, fabrication and materials.

---

[1] It is called fictional meme, because it is a conceptual representation that derives from the interpretation of various ideas from different semantics.

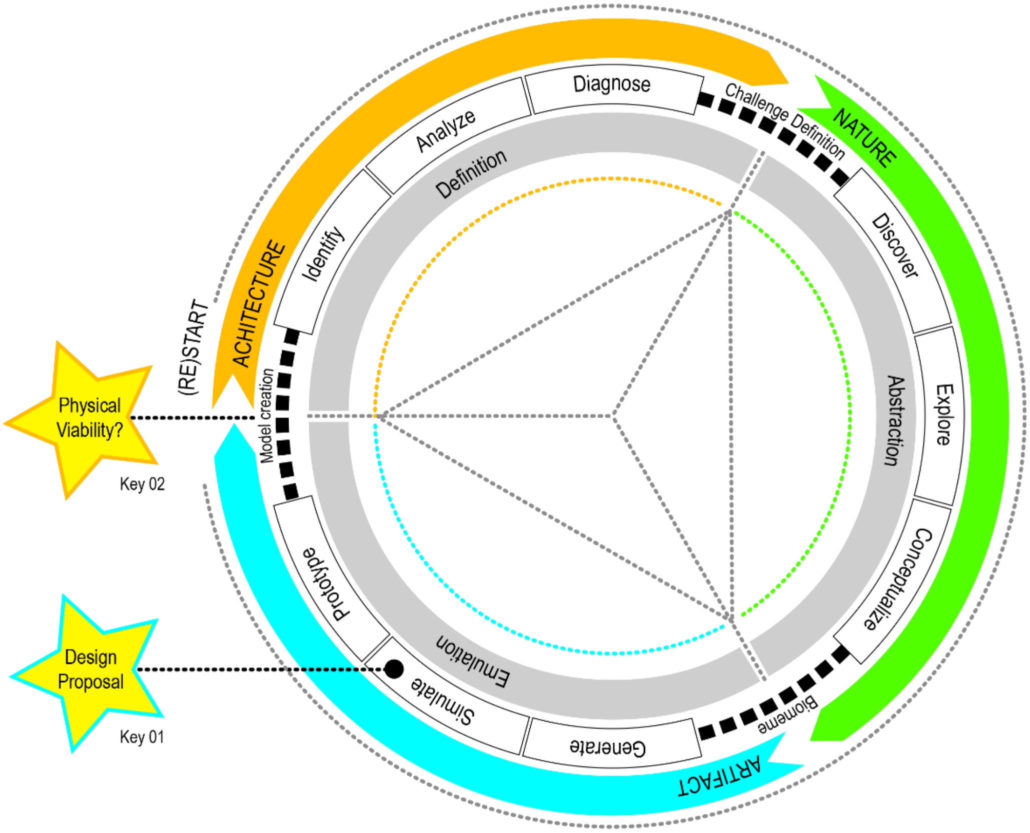

Figure 1. Bio-Shading Concept Design Methodology.

The experience was conducted through a predefined time script having a digital kit as support. The digital kit was composed by several folders containing i) the digital 3D model of the case study building and its context surroundings, ii) the Climate Consultant 6.0 graphic analysis of Lisbon's climate, iii) Ladybug graphical analysis of the studied building south façade, iv) tables and diagrams containing shading façade essential functions, actions and agents, v) a list containing several terrestrial plants types and strategies of adaptations, vi) a Biomimetic *meme* path matrix diagram in order to help the participants to define its fictional *Biomeme*, and vii) two tables listing the main shading systems types of structure and actuation.

The first PoC 1.0 session opened with a chronological presentation, that aimed contextualize the application of biomimetic values and principles not only in architecture but also in other relevant fields such mechanics, design and materials science. The relationship between architecture and terrestrial vascular plants was pointed out as a case study and inspirational motto, and its link was justified based on plants and buildings similar physical condition. Finally, a brief presentation of the most used design and analysis tools, as well as the current CAM resources[2] that enable today architects to perform diagnostic analysis and evaluation on architecture, were also presented and

[2] CAM (Computer Aided Manufacture) resources, in this context refers to the current CAM available machinery – CNC (Computer Numerical Control); laser cutters, 3D Printers, vinyl cutters, robotic arms, among others.

discussed, being pointed its strengths and weaknesses during the architectural design process.

Entering the *Architectural* domain, at the Identification phase, PoC 1.0 participants were presented to the case study building and its context. The selected case study building integrates a proposal for a university residency program, which also houses coworking and services spaces. Located in Lisbon, inside the Cidade Universitária Campus, the analysis target was the south façade of the case study building[3]. To the participants was given a three-dimensional model of the Cidade Universitária Campus. A complete climate analysis of the city of Lisbon, conducted through Climate Consultant (CC) 6.0 software, was presented and explained to the participants[4]. The participants CC material supplied contained annual temperature, radiation, illumination and wind velocity range graphics, sun shading and psychrometric charts, among other informations. At the second phase, Analysis, participants were introduced to the Ladybug analysis charts and diagrams. Based on parametric information, Ladybug can perform real time analysis, providing the possibility to extract two or three-dimensional diagrams, schemes and charts into/over the three-dimensional model. Dry bulb temperature, irradiation, total direct and diffuse radiation, urban shade benefit, shading comfort façade design, wind speed and air temperature roses were the diagrams and charts provided to the participants.

A process of interpretation and analysis was conducted. After a context/climatic study and analysis, participants were invited to Diagnose which were, in their perspective, the shading system main functions for that case study façade. Three base tables (Table 1) were supplied i) containing the shading systems main functions, ii) pointing some of the most relevant shading systems actions and iii) enumerating some of the agents that could trigger these actions. During the Diagnose phase, participants started working in pairs, which triggered some effective discussions over their intentional aspects to the shading system pairs proposals. From this brainstorm, the five groups were able to define their shading system main goals as well as their functions>actions>agents' semantic relationship, achieving at the end of this phase the so-called Challenge definition.

Table 1. Functions>Actions>Agents tables.

	Functions		Actions		Agents
1	Dir. Rad. entry	A	Permeability	a	Translucency
2	Dir. Rad. blockage	B	Reflection	b	Opacity
3	Diffuse Radiation	C	Refraction	c	Morphology
4	Glare control	D	Intersection	d	Structure
5	External views	E	Material	e	Density
6	Natural ventilation	F	Scale	f	Pigment
7	Architectural integration	G	…	g	Pattern

[3] All the information provided about the case study building, not yet built, is based on a rendered image published with the article "Universidade de Lisboa constrói 1700 novas camas", in Expresso Journal, November 3rd, 2018.

[4] The CC analysis used the ASHRAE standard 55 and Current Handbook of Fundamentals Model. This comfort model defines that the thermal comfort is based on dry bulb temperature, clothing level, metabolic activity, air velocity, humidity and mean radiant temperature.

8	Others	H	…	h	Orientation
		I	…	i	Roughness
		J	…	j	Air flow
				k	…

The second part of the first PoC 1.0 session was all about the *Nature* domain. An oral presentation, supported by images and diagrams, aimed to expose and explain terrestrial plants vascular system, its relevance and main functional organs and features. To engage the working groups at the Discover and Exploration phases, an introduction to plants adaptation strategies (morphological, physiological and behavioral) was made, in order to present and explain how to analyze the supplied plant adaptation data survey digital document, as well as how and where to search for the presented or search other adaptation events (fundamental online resources such AskNature , Biomimicry 3.8 , Basic Biology , among others). Given the resources, it was necessary to clarify the process of creation of the *Biomeme*. From the several available surveys, each group was invited, at the Exploration phase (considering the previous Challenge Definition results), to elaborate a *Meme* event table (Table 2), where they selected the plants adaptation events that could resemble their shading system defined functions.

Table 2. Meme Events Table example.

Meme Event	**Adaptation**	**Strategy**	**Main principles**	**Main features**
Bioluminescence	*Behavioral*	*Dynamic*	*Occurs through a chemical reaction that produces light energy within an organism's body.*	*Photosensitive*
Nyctinastic movements	*Behavioral*	*Dynamic*	*The leaves of plants respond to daily alternation between light and darkness by moving up and down.*	*Moviment, open-close,*
Vernation	*Behavioral*	*Static*	*How the leaves are arranged on the buds, folding or curling.*	*pattern*

In order to dissect the selected meme events, participants stratified the events in type of adaptation, strategy, main principles and features. This stratification is essential for the methodology user. This process allows not only to extract the several characteristics and properties of each of the selected memes, as well as transport them through interpretation to the architectural lexicon. Adaptation and strategy will enable the meme categorization in the fields of its actuation. Principles is the BSDM user first approach to an individual interpretation of the meme event, while features are the pattern, material and performative characteristic observed by the BSDM user in that specific meme. After completing this task, the groups were ready to Conceptualize their *Biomeme*. The *Biomeme* conceptualization was produced through the fulfilment of the Biomimetic *Meme* path matrix (Table 3). In PoC 1.0, the Biomimetic *Meme* path matrix crossed the shading system main functions with the selected meme events. Extracted from the previous meme events table, and in addition to the shading system selected functions, the Biomimetic *Meme* path matrix also crossed other inputs meme events information's, such as adaptation and strategies types, pattern, material and performative features. By this process, each group achieved its *Biomeme* through a majority accounting process.

Table 3. Biomimetic Meme path matrix example provided to the PoC 1.0 participants.

selected functions	A meme	B meme	C meme	... meme	Biomeme
1	*x*				*x*
2		*x*			*x*
3			*x*		*x*
4				*x*	*x*
Meme Strategies					
Dynamic	*x*	*x*		*x*	*x*
Static			*x*		
Meme Adaptation					
Morphological	*x*		*x*		*x*
Physiological				*x*	
behavioral		*x*			
Meme Pattern features					
xxx	*x*				
xxx			*x*	*x*	*x*
Meme Material features					
xxx	*x*	*x*			*x*
xxx			*x*	*x*	*x*
Meme Performative Features					
xxx	*x*		*x*	*x*	*x*
xxx		*x*			

After a one-day reflection gap between sessions, PoC 1.0 second session was entirely devoted to the *Artifact* domain. The session was initiated by an oral presentation supported by several reference images over shading systems type of structures, mechanisms and actuations. To the groups was supplied two digital documents containing a synthesized information over shading systems structural types and possible types of actuation. The shading system types of structure document contained a short description, pros and cons of the mentioned type of structure and possible actuation clues of its implementation. The actuation types document contained also a brief description of the actuation, its pros and cons, and some required resources and knowledge for its implementation. The following period was completely devoted to the groups shading systems design. From the PoC 1.0 five different projects, with different levels of development, emerged. Letters, A, B, C, D and E will be used to mention them. A brief description of the groups produced work will follow.

03 The projects

3.1 *A Group (Luísa Almeida and Ana Castanho)*

The A group shading system selected functions were related with the system ability to block/entry the direct solar radiation, enabling a convenient and constant external view connection, ensuring building natural ventilation. To achieve these performative functions, the selected actions were: permeability, intersection, material and scale. Their idea was to design a system that could be either permeable to light or opaque in different moments of the day. During the *Nature* domain, the group selected *memes* were: bioluminescence, epidermis, nyctinastic movements and vernations. Their fictional *Biomeme* was a system with permeable/opaque ability, scale variations, with dynamic strategies and behavioral adaptation abilities, that should be materialized through a multilayer and perforated system, using porous material properties and open/close mechanisms. During the Generate phase, the designed system was a triple-layered façade, composed by bi-directional radial foldable elements, organized by three different scales (Figure 2). The foldable elements, were composed by triangular frames, coated by two different materials. When clockwise rotated the elements exhibit a perforated textile, when counter-clockwise rotated the elements exhibit an opaque textile. The system was conceived to automatically respond to the sunlight position.

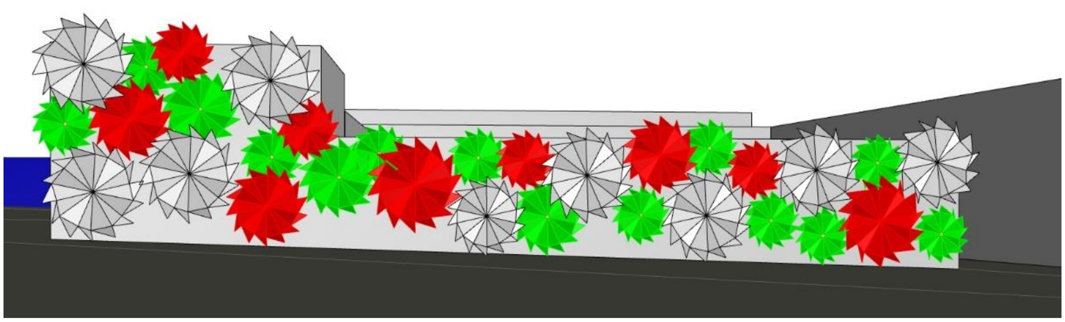

Figure 2. A Group - PoC project: Shading system design proposal.

3.2 B group (Susana Neves and João Parcelas)

The B group considered that the most relevant shading system functions for the case study façade should privilege the external views, natural ventilation and a convenient architectural integration. Their selected actions were permeability and material. Permeability enables the connection interior/exterior and natural ventilation, and material opens a wide range of possibilities for the shading system performance and to its proper architectural integration. To perform the selected actions, morphology and opacity were the elected agents. The selected *memes* were: trichomes, nyctinastic movements and diaheliotropism. The defined *Biomeme*, privilege external views connection, natural ventilation and architectural integration, using dynamic strategy and behavioral adaptation, through an adaptive pattern, composed by a flexible material with tracking features. The proposed solution was a stretch/bend vertical system, composed by perforated and translucency flexible materials (Figure 3). The façade was covered by vertical strips (all with the same width) and the system worked in one stretch/bend consequent loop. This loop was controlled by a sun tracking system. When direct sunlight needed to be blocked the translucency material was stretched, and the perforated bended, when sunlight represents no harm, perforated material is exhibit and translucency material is bended.

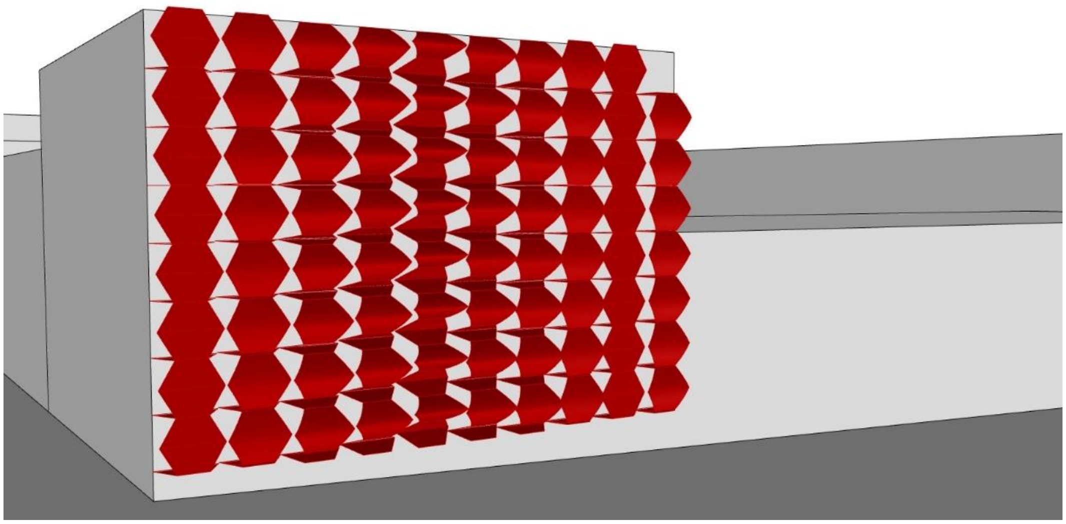

Figure 3. B Group - PoC project: Shading system design proposal.

3.3 C group (Raquel Martins and Carlos Sequeira)

Direct radiation entry, diffuse radiation, glare control and natural ventilation were the main functions considered by the C group. In order to perform these functions, the selected actions were permeability, material and scale. The selected agents were density, pattern, opacity and structure. Permeability was worked by density and pattern, material by the opacity and scale through the structure. The selected *memes* were: canopy plants, endothermic, xylem, superhydrophillic, phloem and bioluminescence. The created *Biomeme* aimed to manage the direct and diffuse radiation entry, glare control and to ensure natural ventilation through the façade. The intended strategy was dynamic, with physiological adaptations. Features should resemble a multilayer bubbles pattern, using flexible and/or sponge materials, enabling unidirectional movements and storage behavior. The fundamental idea was to create a living curtain façade, that using solar radiation, could heat collected rainwater for domestic use.

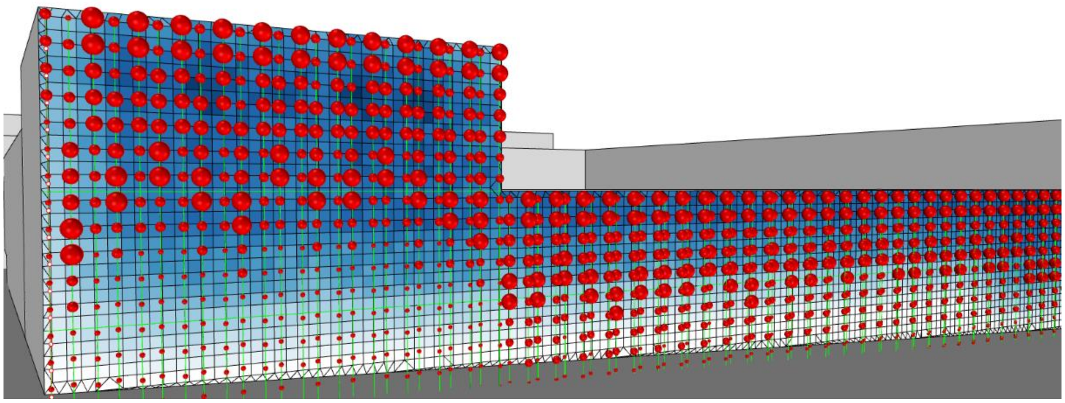

Figure 4. C Group - PoC project: Shading system design proposal.

3.4 D group (Diana Gabão and João Sousa)

D group diagnose the case study façade with the necessity of direct radiation blockage, external views connection, natural ventilation and a convenient and adequate architectural integration. To achieve these functions their selected actions were: permeability, reflection, refraction and material. Since a very early stage, material was an important factor due to its potential to transform and achieve almost infinite viable combinations. To perform the pointed actions, the elected agents were translucency, morphology, pattern and density. At the *Nature* domain, the group focused in morphology, pattern and density actions, and selected diaheliotropism, endothermic, asymmetry, stoma and epidermis as their memes. Their *Biomeme* aimed to respond to direct radiation, maintaining external views connection not forgetting the architectural integration. To design the shading system a static strategy was conceived using morphological and physiological adaptations. The shading system would operate through a multilayer pattern, composed by a hard material, with concentric movements and/or cellular performative features (Figure 5).

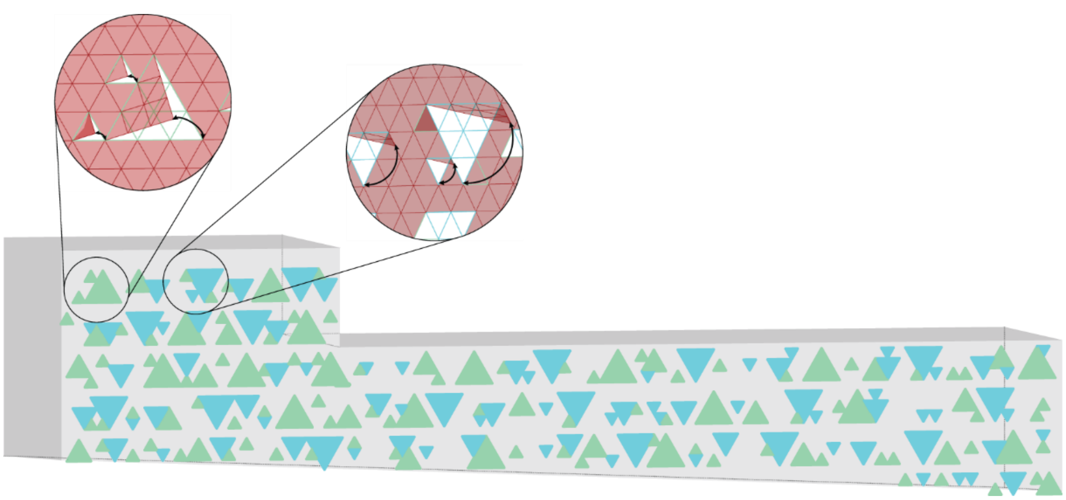

Figure 5. D Group - PoC project: Shading system design proposal.

3.5 E group (Filipa Osório and Pedro Frutuoso)

E group began their project studying the sun rays of the south façade during summer and winter solstices. Their selected functions were the ability to control entry and blockage of solar radiation as well as indoor glare control. To achieve these functions, the selected actions were permeability, reflection, intersection and material. Material translucency, a structure capable of producing intersection and reflection, and a pattern with an adequate density enabling permeability were their action>agent strategy. Their plants selected *memes* were the deciduous plants, whorl, bark trees, diaheliotropism and the nyctinastic movements. The conceived *Biomeme* aimed to control not only entry and block solar radiation as the glare effect, using dynamic strategies, through the implantation of behavioral adaptations. The shading system would have a random pattern, made of flexible materials in order to enable a bidirectional movement.

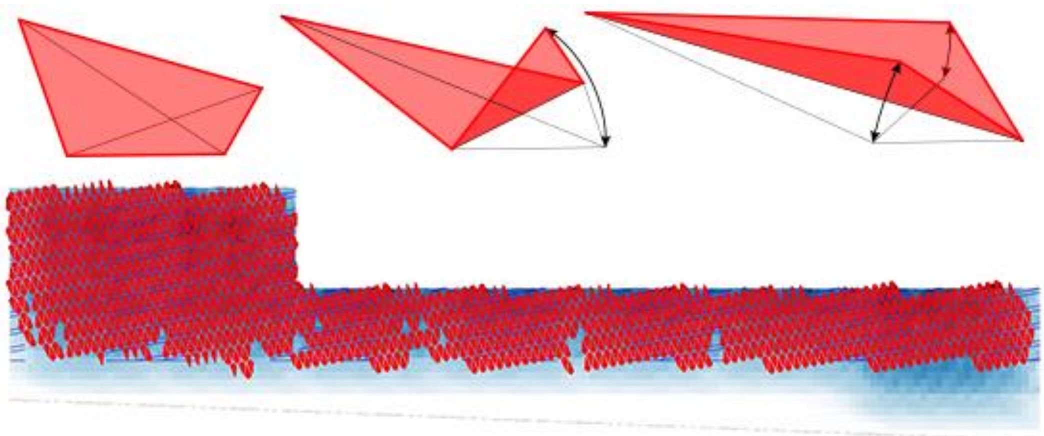

Figure 6. E Group - PoC project: Shading system design proposal - diamond perpendicular movements.

04 Conclusions and clues

PoC 1.0 provided several valuable information's, regarding the BSDM 1.0, but most of all regarding its application procedure and digital tool kit. From the PoC 1.0 experience and from the participants and researcher's evaluation, some changes and complementary material have to be (re)created for a forward Bioshading Concept Design Methodology 2.0:

- During the Architectural domain, Diagnose phase, more than provide lists with the primary functions, actions and agents, its mandatory to explain those items and to show, by exemplifying their possible correlation. To explain the different functions, actions and agents, a glossary should be created and open to the methodology users. In order to exemplify the correlation between the elements, an illustrative diagram should be presented;
- Regarding Nature domain, a diagram that links the Meme events table, from the Exploration phase, to the Biomimetic Meme path matrix, from the Conceptualize phase, would improve user's efficiency and optimize noncreative time during the process, accelerating the Biomeme creation;

Artifact domain requires time. PoC 1.0 initially aimed to achieve the Simulation phase during the second session. However, PoC 1.0 participants used the

Simulation assigned time (1 hour) to the Generate phase. Still, the designed projects were sustained by a context and climatic analysis, which make them more efficient and responsive to their surrounding environment context. Other important note about this phase, it's the high relevance of the user's experience. A digital fabrication skilled user more easily integrates technical information in its design, as well as a skilled parametric designer, more easily design motion intentions.

05 Acknowledgements

The authors would like to thank the enthusiasm, dedication and passion with which all the participants have devoted to this BSDM PoC 1.0. Thank you very much Ana Castanho, Luísa Almeida, Susana Neves, João Parcelas, Raquel Martins, Carlos Sequeira, Filipa Osório, Pedro Frutuoso, Diana Gabão and João Sousa.

06 References

Benyus, J., *Biomimicry: innovation inspired by nature*. HarperCollins Publishers Inc., New York, 2002.

Dowlen, C. A., "What is design?", in *Nature and Design*, M. A. Collins (ed.), 2004.

Eroğlu, A. K., Erden, Z., & Erden, A., "Biological System Analysis in Bioinspired Conceptual Design (BICD) for Bioinspired Robots", *Control Engineering and Applied Informatics*, 13(2), 81-86, 2011.

Júnior, W., & Guanabara, A., "Methodology for product design based on the study of bionics", *Materials & Design*, 26(2), 149-155. doi:10.1016/j.matdes.2004.05.009, April 2005.

Kolarevic, B., & Malkawi, A. M., *Performative Architecture: Beyond Instrumentality*. New York: Spon Press, 2005.

Migayrou, F., *Architecture Non Standard*, Paris: Centre Pompidou, 2003.

Oxman, N., *Material-based Design Computation*, PhD Thesis, Massachusetts Institute of Technology, MIT Cambridge, 2010.

Oxman, R., "Naturalizing Design: In Pursuit of Tectonic Materiality", Naturalizing Architecture, M.-A. Brayer, & F. Migayrou Orléans: Hyx (ed.), 2013.

Thompson, D., *On Growth and Form*, Great Britain: Cambridge University Press, 1942.

Vattam, S. S., Helms, M. E., & Goel, A. K., "Nature of creative analogies in biologically inspired innovative design" in *Proceedings of the 7th Conference on Creativity & Cognition* (pp. 255-264). Berkeley, California: ACM. doi:DOI: 10.1145/1640233.1640273, 2009.

[1] https://asknature.org/strategy/structures-optimize-material-use/#.W5FEbuhKhPY

[2] http://biomimicry.net/