Adaptive Pneus

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HARDWARE

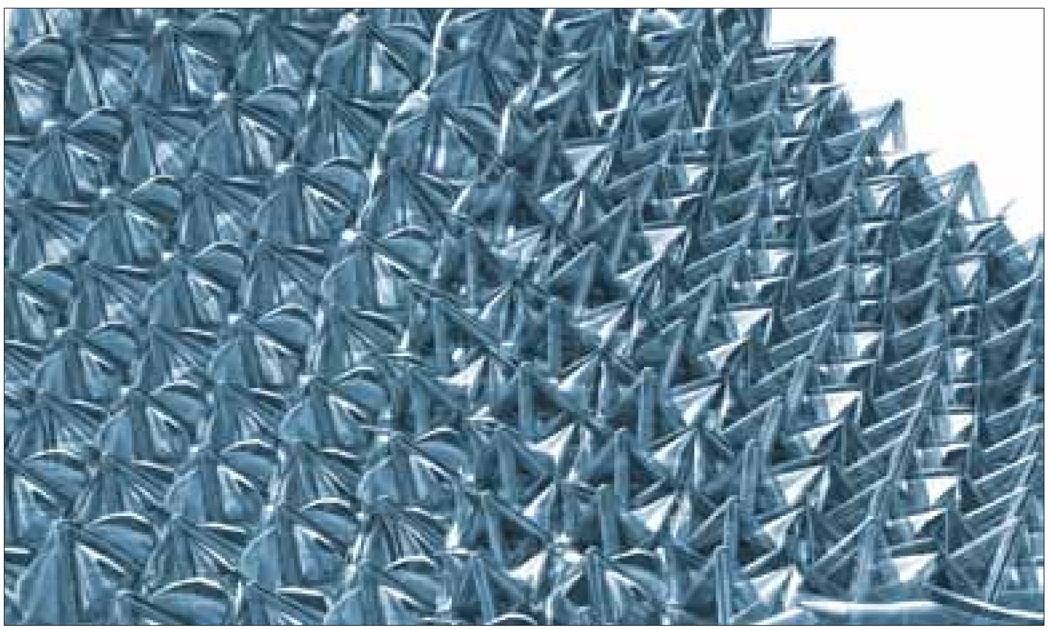

Figure 1 proliferation of the components generated on a surface in relation to sun and wind behavior. Complex behavior of the system has emerged from its simple components.

ABSTRACT

The research focuses on the performative capacities of a pneumatic material system in regards to the specific environmental conditions.

The use of Adaptation as a mechanism to modulate environmental performance was the main focus of the design process and research.

The location of the sun during the day acts as a trigger to adapt the system, allowing the system to passively augment the environmental conditions.

A new form-finding method that combines digital and material processes has been the main method by which the experiments were undertaken. This approach necessitates a dramatic shift in the architectural design, from producing static to environmentally responsive objects. It requires a shift in thinking from buildings as static and non-active systems to material system existing over time within specific environments capable of complex environmental performances.

1 INTRODUCTION

Current and conventional buildings are mainly static and inanimate forms that vary slightly in shape according to extrinsic stresses. Their intrinsic nature builds up an interior condition that is incapable of adapting to the environmental changes throughout the day. The Inability of static and unresponsive conventional buildings, introduces the use of environmental services such as mechanical cooling and heating devices. These devices are deployed in order to overcome the inadequacy of various building forms. The application of responsive systems capable of reacting to the external environmental conditions provides a great opportunity for interior modulation via passive cooling and heating means (Wigginto 1988).

Currently 'smart' and 'responsive' systems are at the forefront of scientific and engineering research. Despite their progress in the past few decades, these systems are still working as additional shading and ventilation devices. In the majority of cases, these system and devices rely on energy-hungry mechanisms to operate, further straining depleting resources (Jeremidis 2004).

The word intelligent was first used to describe buildings at the beginning of 1980s and has been developing as a concept ever since. Recently the use of Smart materials has begun to introduce ideas of self adjustment and responsiveness into design principles. The conventional paradigm of intelligent buildings is closely related to management systems and their methods of controlling complex interior conditions. Such systems posses active controls, allowing the motorized action of what may be called subordinate devices and appliances to be synchronized for environmental performance. (Wigginto 1988).

The research presented here is somewhat different to the traditional uses of intelligence and responsiveness. Here adaptability relates to the responsive action that affects the performance of the whole building and, therefore, holds a much closer relationship to the biological and natural ideas of responsiveness.

This is exemplified by various biological systems such as the thermoregulatory system of the human body, such mechanism can also be seen within other natural examples. Sensing and activating are nature's predominant methods of responding to its conditions.

Within our system, the adaptation takes place in each component. This is done by utilizing local resources; such as making use of the impact of direct sunlight on the system. Detection and reaction are embedded in each cell and responses take place locally and independently. These responses are further developed at the regional and global scales, allowing for distributed intelligence to occur across the whole system.

This allows for potential modulation of light, heat, sound, and ventilation via the simple geometrical manipulation of components both locally and globally without the use of energy-hungry electromechanical devices.

This research commences by questioning and challenging the conventional methods of building design that would require further energy-consuming mechanisms to create suitable interior conditions. It therefore explores a new approach which integrates form generation, material behavior and capacity, manufacturing and assembly, to deliver a modulated environment suitable for occupation. Such environments would no longer rely on secondary and tertiary mechanisms for further modulation.

We can focus the research and its reliance on natural systems as examples of systems which are already capable of responding to their immediate environment, through a number of simple questions.

1-How can a living organism actively adapt to its environment while having a robust and effective structure?
2-How can they respond to continuous changes within their environment without collapsing?
3-Can a building actively respond to external environmental stimuli while still effectively performing structurally, without using energy-consuming electromechanical devices?

In contrast to traditional engineering and design methods, in biology, adaptation to the environment and structural performance of a system are not opposing terms. They are embedded characteristics of natural systems and contribute for the formation and evolution of organisms with regards to their innate material properties. This requires revisions of the traditionally dominant notions of the structural design, which are stiffness and efficiency. "Stiffness in engineering terms implies that structural members are optimized so that they do not easily bend and efficiency characterizes the preferred mode of achieving structural stiffness with the minimum amount of material and energy." These definitions are in direct contrast to the aspects discussed above which can be learned from natural systems. Natural organisms are driven by multiple criteria for form generation and structural behavior, and performance is inherent.

Instead, the notion of effectiveness will be introduced for finding the best possible answer according to the multiple criteria (Weinstock et al. 2002).

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A comprehensive understanding of inherent potential and limitation of material properties is critical when integrating performance derived from natural systems into form-finding methods.

In nature, materials can display varied characteristics without change to their chemical makeup. The difference then emanates from its arrangement. Nature demonstrates masterfully how one and the same material can behave differently due to changing conditions and requirements. The performance of natural systems is based on such structural differentiation, enabling them to react to their immediate environment, as well as bearing structural loads and not collapsing under unanticipated phenomenon. The question remaining is how can the immense potentials existing in natural systems be instrumentalized for architecture to deliver environmentally responsive buildings? (Weinstock et al. 2004)

Pneumatic material systems are abundant in nature for both structural and adaptation purposes. In the building industry, pneumatic structures are among the lightest and most economically known. They present one of the lightest and relatively cheapest means for spatial organization and environmental modulation. Their properties in regards to bearing tension and compression loads at the same time make them one of most interesting material systems.

The experiments started with interest in exploration of pneumatic material systems. It focuses on unfolding the performative capacities inherent in the pneumatic material system with regards to the specific environmental condition. Ecological adaptation is the principle of this design process. A different approach from the traditional architectural and engineering design process has been taken in order to understand the relationship between the material system and the environment. Stimulation of adaptation to modulate environmental and structural performance by the devised pneumatic material system has been the main focus of the design process. This has been examined in an empirical design method which analyzes the construction of the material with regards to its geometrical features, assembly logic, construction limits and interaction with environmental conditions through natural stimuli.

Both physical and generative computational experiments and analyses contribute in the form-finding method used for this project.(Hensel and Menges 2008).

A new form-finding method that combines digital and material processes will be the main method by which the experiments will be undertaken. It requires the recognition of buildings not as singular and fixed bodies, but as complex energy and material system that have a life span, and exist as part of the environment. In this method, exploration of elements and components followed by proliferation are informed from material behavior, assembly logic and component geometrical features, as well as its performative behavior under specific climatic conditions. The final design scheme forms up with regards to its performance and effectiveness under a particular environmental situation. Performance will be measured via a determinant multi-criteria that interrelates the material system's assembly and manufacturing logic, spatial and environmental factors. This is different from traditional form-finding methods which mainly focuses on mono-parametric structural behavior. A crucial aspect in multiple-parameter experiments is the redefinition of the notion of efficiency. For instance, if only one structural parameter needs to be considered, like Gaudi's hanging models, the performance of the model can be optimized to a specific force-case. In multi-parameter set-up, each result is a negotiation towards a best possible overall performance, with a great deal of redundancy built into the material arrangements, so that shifts from one force scenario to another can be accommodated.

2 PROJECT'S DESCRIPTION

In order to find inherent characteristics and assembly logic of pneumatic material system, initial experiments have been undertaken. These experiments were done using both physical and digital method to understand and instrumentalize the potentials of pneumatic material systems.

Two main types of components were derived from initial experiments and studies. Porous structural and opening components (figure 2).

Having combined the two, the final semi static/semi dynamic component was found. Then the structural performance of the achieved model was empirically tested by building a 1/1 prototype roughly measuring 3 * 3m (fig. 4).

Inspired by muscle movement in nature, a similar contraction and expansion mechanism was developed. Direct sunlight radiation increases the turgor pressure exerted on the interior membrane of the components. Once the pressure change is detected by pressure-

Figure 2 Perspective view. Potential use of Adaptive pnue as the climatic skin.

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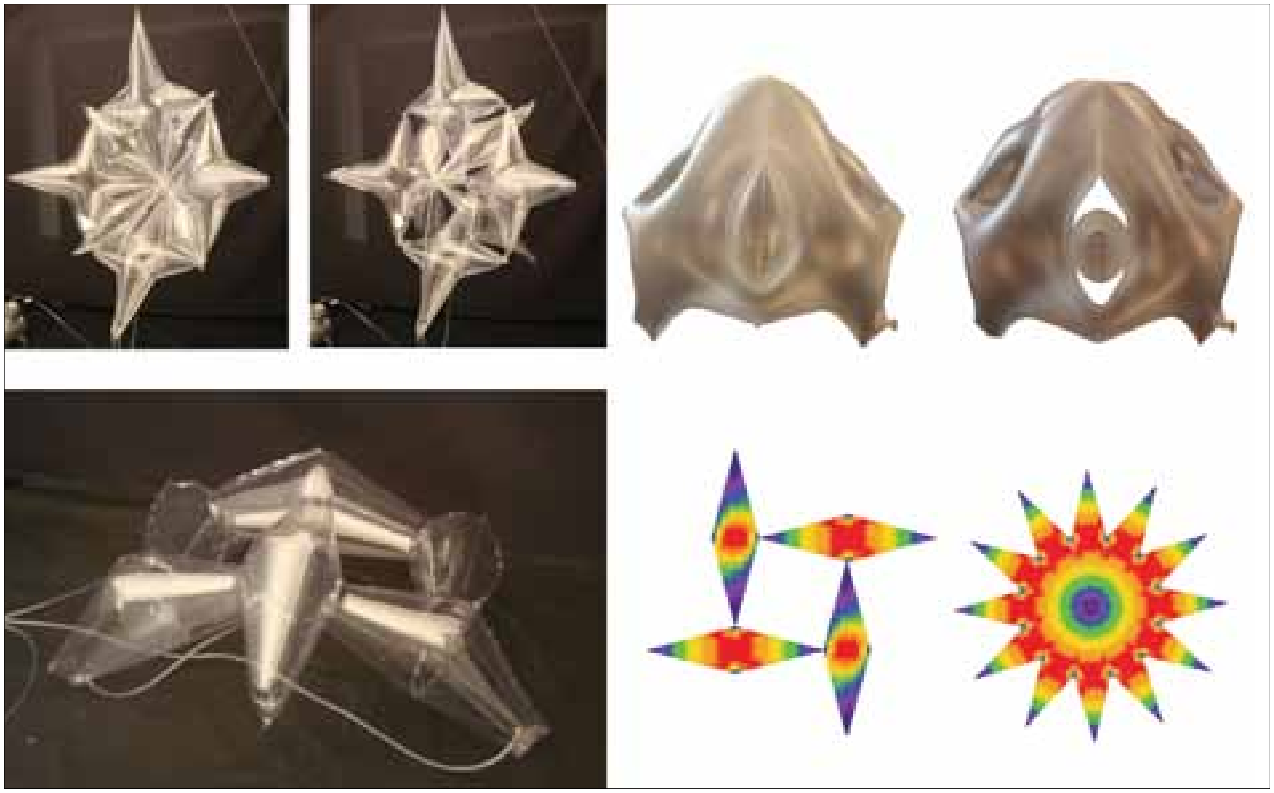

Figure 3 Structural studies of Pneumatic Component. Base studies for finding opening part and structural part of the component.

Figure 4 3x3 meter Adaptive pneumatic prototype. Installed in AA Emtech Studio garden.

sensitive valves in the air-management units, compressors provide the air through pressure-release valves. This allows air to travel to the pneumatic muscles and the component opens.

This reaction does not take place during winter months due to the decreased turgor pressure within the pneumatic cells, allowing the system to be potentially deployable all year long, responding with seasonal changes and temperatures.

This part of our studies was completed by the development of a 1/1 prototype of the component, measuring 1.2 * 1.2 m (fig. 5).

Figure 5 1/1 prototype of the final component, 1.2 m * 1.2 m

2.1 PERFORMANCE ANALYSIS

Parametrical relationships between the components define the behavior of the system in the given environment. Scrutinizing the behavior of the material system in the specific environment helps to understand the relationship between physical characteristics of the system and the surrounding environment. This leads to the parametrical differentiation of the components in the local scale that reinforce the functionality of the system in the regional and global scale. These sets of experiments mainly investigate the behavior of the system in local scale to work out the differentiation rules of the components in the given environment. They comprise of CFD analyses and shadow-casting experiments.

2.2 SHADING EXPERIMENT

Shading plays a significant role in passive cooling. In the devised material system, light penetration is actively controlled via injection of smoke into the structure when necessary. This allows for the material system to adapt the level of transparency based on the intensity of sunlight.

However, if the components are fully translucent, they are still porous when direct sunlight hits them. This causes undesired direct sunlight to penetrate the interior space.

Through a series of digital experiments, the behavior of the components were understood, and via some geometrical manipulations of the height and radii, variations in components and their behaviors were found in their ideal situation (fig. 6).

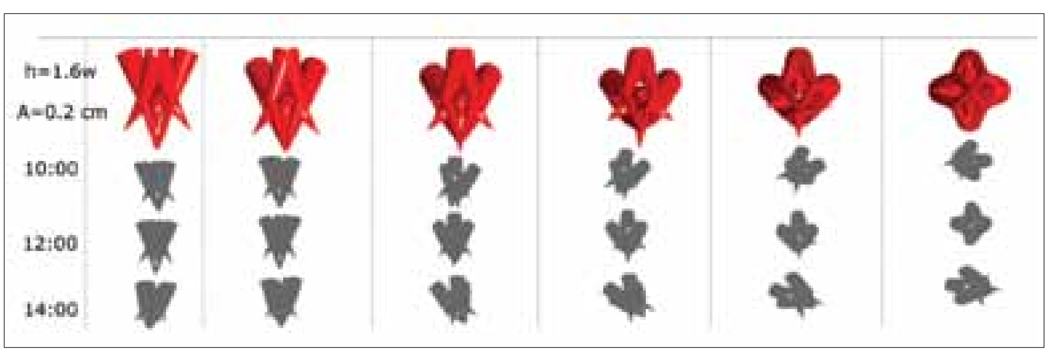

Figure 6 Shadows in created form the components in different vertical angles towards the sun, after geometrical manipulation

2.3 CFD ANALYSIS

CFD analysis allowed us to study the relationship between different sized components and their behavior under prevailing wind, based on specific site conditions. Geometrical manipulations include height, opening angle and component angle variations.

The results of the experiments indicate rules for component differentiation on the global scale. The components are oriented towards the prevailing wind, when located at the windward side the angle of openings should decrease, while increasing when located on the leeward. This rule increases performance of the components for natural cross ventilation. In addition, if the components stand with less than 45° against the wind, 4 opening elements on four sides contribute to natural ventilation. However, once they stand with an angle greater than 45°, the leeward side openings gradually interrupt with the functionality of the components; therefore, they will be closed (fig. 7).

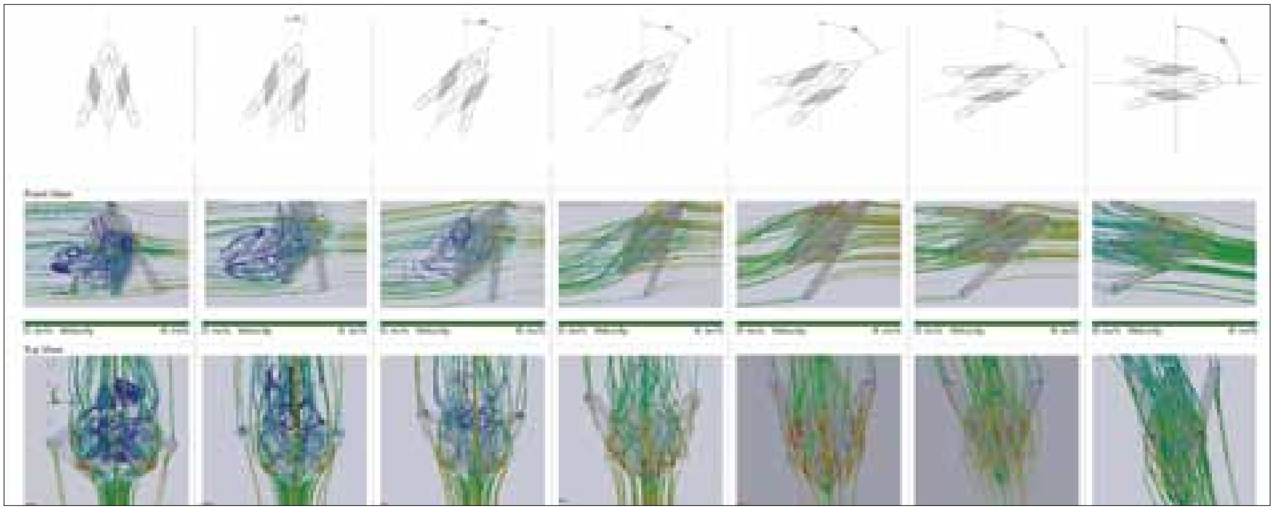

Figure 7 CFD Analysis of the component in different angle variation and opening angle to examine the performance in different circumstances.

2.4 DESIGN PROPOSAL AND GLOBAL PERFORMANCE ASSESSMENT

Having finished the material system study and manufacturing, we employed the material system for an architectural application to test performative and environmental modulation potentials of the system under specific environmental situations. The project attempts to moderate the interior condition via controlling the light penetration and employing natural ventilation as a means of passive cooling, therefore, decreasing demands for electromechanical devices. The roof cover also improves the residents' living condition's by creating roof garden space usable for inhabitants.

By taking macro- and micro-climatic features of the chosen site into consideration, the system was applied on a collection of existing buildings as the second skin that creates a climatic envelope. Global surface morphology formed with regards to the structural and environmental performance of the material system and the project's physical program. Further differentiation of the local scale in accordance with the parametric interconnection rules improved the functionality of the project.

2.5 MULTIPLE CRITERIA AND GEOMETRY FORMATION

The global morphology form is based on multiple criteria, which are in direct relation to the material system's properties and capabilities. Multiple parameter experiments involving many forces acting together such as spatial, material, structural, and habitation characteristics are approaches for the project.

The multiple criteria used in this project are comprised of
1- Spatial quality and height limits
2- Assembly and manufacturing constraints which have to respond to the complicated boundary condition and limits the range of iso curves building the envelope
3- Structural performance
4- Environmental performance in which activation of cross-ventilation throughout the day, distribution of fresh air and light filteration of the material system is analyzed

From the criteria the first three factors are considered the dominant criteria which build up the first random geometry. These three criteria have higher priority as the second skin surface (design proposal) is valid and feasible if and only if it meets the primary criteria.

Once the geometry satisfies the requirements of the initial criteria, its environmental performance has been analyzed to enhance its effectiveness. In so doing, location of opening in different times of the day should be indicated. Once the location of the openings is understood, the designed surface can be analyzed based on different openings throughout the day (fig. 8). The performance analysis provides the feedback for the next iteration of form generation. Of course, the design loop starts again and the modified geometry should pass through initial criteria and then assessment process. this feedback-form generation loop carries on until the desired form emerges.

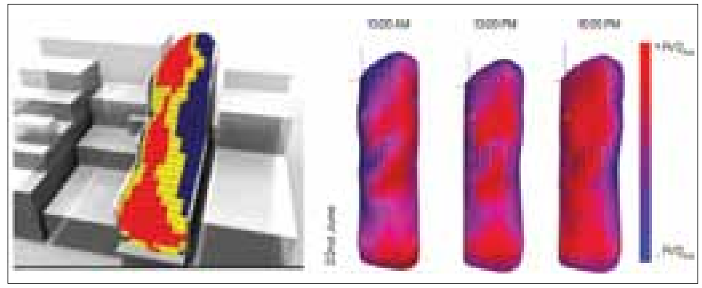

Figure 8 Light Exposure Analysis—In Global Scale. in different time of the hottest day, and Numerical Value driven from exposure of the surface towards the sun at 12:00 PM. This indicates the location of openings at that time

Solar analysis enables us to digitally simulate the location of the openings for different times of the day throughout the year. Location of openings should be measured with regards to the angle of each cell towards the sunlight. In this experiment we aimed to anticipate the location of the opening throughout the day based on three sample times (10:00 AM, 12:00 PM, 16:00 PM), (fig. 7). Indication of opening location throughout the day allowed us to analyze envelope ventilation performance under a virtually created micro climate based on the chosen site.

The first set of experiments revealed that the initial morphology is suffering from lack of cross-ventilation in the morning and bad distribution of fresh air within the envelope.

The data driven from the first set of analyses was used for the modification of global geometry for the next iterations. Geometrical manipulation happened by utilizing a cellular automata algorithm. After some iterations of the global morphology, the desired form emerged that benefited from active cross ventilation through the day and distribution of fresh air within the envelope (fig. 9).

Parametrical differentiation of the components, obtained in the local performance analysis, allowed for better ventilation and shading performance. Global shading analysis revealed that the majority of the surface (more than 80%) is covered by shadow in the hottest period of the day during the course of the summer, this proves to be a very successful result.

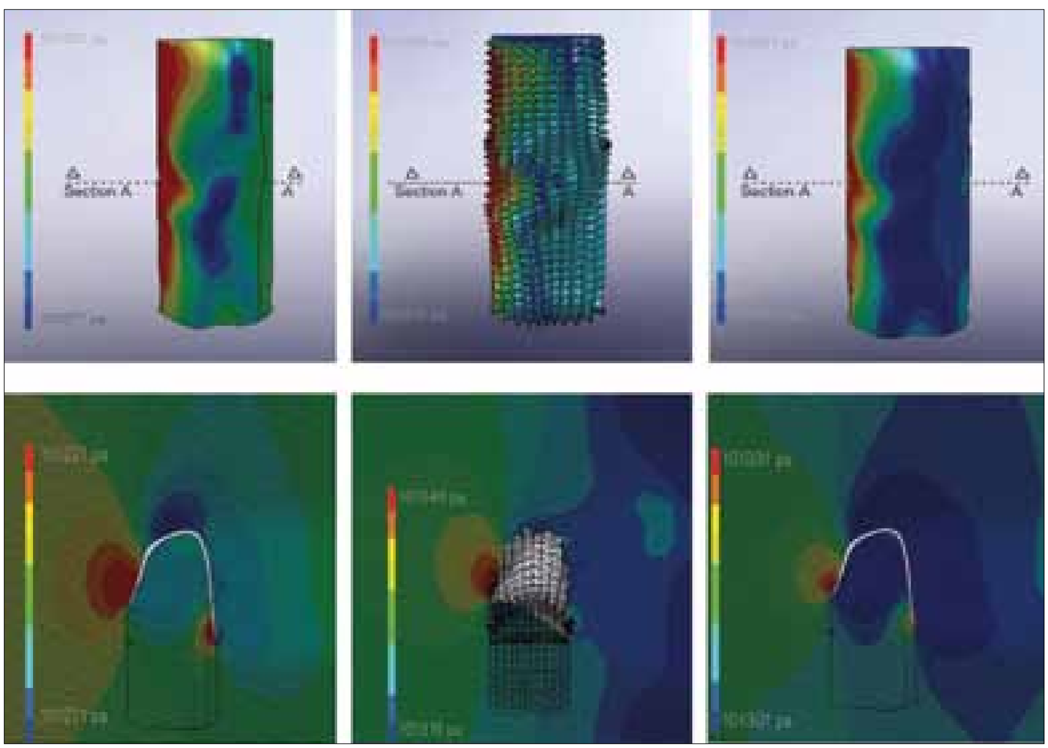

Figure 9 CFD Analysis of the Global geometry (surface) which the components proliferate on. The openings are calculated by information driven from total sun light analysis of the surface

CONCLUSION

Through the exploration of the characteristics of this pneumatic material system, particularly in the field of structural performance and adaptability, a material system was developed that is capable of bearing self-load and responding to the environmental conditions. In doing so, it takes a different approach to traditional engineering methods.

Two main types of experiments were devised that focused on structural and adaptable capacities of the material. These included physical and digital form-finding experiments that provide generative feedback loops for the purpose of various geometrical deformation studies in different circumstances. This enabled the project to develop through a bottom-up process. By combining the two experiments a final component emerged. Structural tests of the final components followed by development of opening mechanism completed the physical experiment processes. Studying various types of movement in nature such as variable stiffness, Reversible and Irreversible Movement Without Muscle and Movement with Muscle, helped to develop the movement mechanism for the components.

Employing a pneumatic muscle that is made of a flexible membrane attached to the main component, a reversible movement abstracted from the natural mechanism of muscles, takes place. Pneumatic muscles are triggered from the amendment of existing turgor pressure exerted on the interior walls of the pneu membrane. The interior pressure increase is driven from the exposure of the components towards the direct sunlight. Then, proliferation of the components on various surfaces revealed the potentials and limitations of the material system for covering the spaces and environmental modulation.

A detailed investigation of different manufacturing possibilities lead to the construction of a 1/1 prototype supplied by an appropriate manufacturer. The material system proved to be viable and an alternative solution of covering fully enclosed interior spaces, capable of reacting to the immediate environmental conditions. This system is potentially capable of environmental modulation via natural ventilation and light-penetration control.

The final step of the research was the application of the developed system as a cover for a number of houses on the chosen site. The design proposal intended to potentially improve the interior condition of existing improperly constructed buildings. The insertion of a second cover on the existing buildings made the adaptable pneumatic system a potential modulator between the interior and exterior environment throughout the year. By creating a medium space on the roofs that is a private usable space, design proposal strived to improve quality of life for the inhabitants.

From the form generation under specific site and boundary conditions, the global morphology emerged and through iterations, geometrical manipulation and performance assessment the functionality of the surface in terms of natural ventilation was improved. Finally scrutinizing the behavior of the system in the local scale in various circumstances under the climatic condition of the site, components were differentiated to enhance the functionality of the project in terms of natural ventilation and shadow casting. Through the parametric manipulation of local elements, the functionality of the whole system was improved.

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