ISBN 978-93-84468-11-8
Proceedings of International Conference on Architecture And Civil Engineering (ICAACE'14)
Dubai, December 25-26, 2014, pp. 51-56

Pinecone from Nature to Construction: Inspired Design Strategies for a Sustainable Roof

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Abstract: *Concerns about the global warming phenomenon in accelerating the climatic changes has highlighted adaptation ability as a way of forming comfort levels to survive in different conditions. This leads to research into the principles of Biomimicry Science by extracting bio-strategies from a pinecone as a natural concept and reflecting them onto building design for better performance. The adaptive ability of buildings is developed through this study to achieve thermal comfort level and reduce energy consumption. Therefore, strategies are extracted through the concept's anatomic analysis while being validated by simulating the impact of the new strategies in improving building performance in Abu Dhabi. Ecotec simulation found the ability of a new roof with 0.610W/m².k U-value in reducing energy consumption by 38% while increasing satisfaction levels. This research project creates a new pathway of natural solutions integrating the construction field with the environment, while recommend new regulations for designing adaptive buildings in hot humid countries.*

Keywords: *Biomimicry, Design strategies, Adaption ability, Energy Consumption.*

1. Introduction

Nature has the most professional ways in solving life's problems, with success over billions of years. In terms of survival, a naturally balanced adaptation mechanism works between organisms and environment, integrates the structure and behaviour of the organism. That leads to identifying "life creates conditions conducive to life" as the main method of Biomimicry in relating survival ability to respecting environmental physics, limits and boundaries (Baumeister et al. 2013). The pinecone as a humid sensor forms a hygroscopic skin that controls the comfort of the in-core in variable climatic conditions. Recognising that performance highlights the ability of controlling building indoor environmental quality (IEQ) by use of envelopes. One of the main concerns in designing sustainable buildings is maintaining the indoor comfort level through climatic changes by using passive ventilation for low energy consumption. Hot humid climatic zones present a major design obstacle in balancing outside and inside conditions especially in summer where active ventilation is the only way to survive in such a climate as Abu Dhabi. Recent interest in the UAE of forming an effective green assessment tool for the GCC region has highlighted the importance of presenting new design strategies enhancing envelope properties to reduce energy consumption. This project builds on imitating the performance of the selected concept by analysing and reflected inspired strategies on building roof designs while examining the new roof performance in contrast with common regulated roofs in the UAE, in terms of reducing energy consumption and achieving thermal comfort level.

2. Literature Review

The pinecone was pointed as a design inspiration key for the lattice shell. Hensel, Menges and Weinstock (2006) presented the Metapatch project, to create a new protocol for large prototype construction. The study used rectangular wood elements imitated from pinecone vents. The elements performance was examined in large geometry under a specific force recorded elements' size, thickness, and fibres orientation & bending impact on performance. Hensel and Menges (2008) presented a study of the responsive surface structure under moisture to examine the behaviour of rectangular wood elements. Changes in the humidity rate can automatically raise the hygroscopic behaviour of the woody elements. That led to identifying a new strategy for a responsive skin of buildings with a mechanical or electrical control to give buildings an adaptive ability with environmental changes imitating the open and close mechanism of pinecone vents. Menges (2009) improved on the previous ideas to get a smart wood lattice shell that has a specific dynamic and flexible behaviour. The wood elements and their abilities to bend and stretch were investigated as inspired design strategies to change geometric shapes from wavy to flat surfaces without any force or hoists.

In terms of energy consumption, Schittich, Lang and Kruppner (2006) reported on the ability of controlling a building's required energy by improving the thermal properties of the skin layers and their fixation. That can reduce 40% of HVAC and 20% of lighting energy consumption in a hot climate.

3. Pinecone Strategies

The pinecone's adaptive mechanism points to humidity and temperature as the main activation factors classifying the cones as natural humidity sensors. The active and passive conditions of pinecone genders depend on the ability of small pockets to absorb water from air. That helps to close and open vents in order to maintain the central thermal comfort level. The location of those pockets inside or outside the vents is the main differences between genders. Pocket cells are bounded by a thin layer organised with a water entrance and exit according to the humidity and temperature level of the surrounding environment. In addition, the layer filters water to be valid for metabolic processes (figure 1).

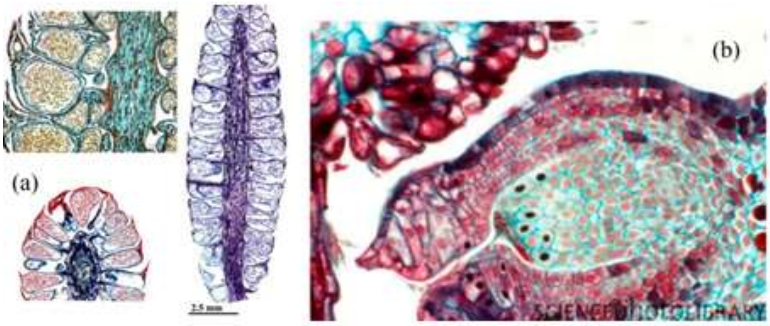

Fig. 1: Pine cone - Microscopic shots. (a) Cross section. (b) Cells ability of absorbing water. (Science Photo Library (SPL) 2012).

Reyssat, and Mahadevan (2009) studied pine vents behaviour under humidity changes. That analysed the vents into two layers work as protective elements. High humidity levels can encourage the outside vent to bend about 100° while stretching to 20% longer than its length in dry conditions. The research presented the relation between a vent's thickness and its ability to shrink and expand. The smaller the thickness of the vent is, the greater the ability to bend and extend. That led to highlighting 22°C with 40% RH as the starting dry level that can encourage a male pinecone to open.

Furthermore, the vents also have a dynamic ability to bend according to wind direction to pollinate seeds while providing appropriate ventilation for the cone. The structure of pinecone vents distributes air to provide central natural ventilation. The down side growth of the pinecone in its vertical direction classifies it as natural rain drainage. The ability to grow and expand is mainly depended on circular order of the vents grids look like layers covering 70 % of each other to minimise heat loss and gain for the cone. The single side vent fixation gives vents the flexibility to open and close, while encouraging growth in two opposite directions (Biomimicry Institute 2011). The woody surface of the pinecone helps to highlight common wood proprieties such as: low conductivity, low radiation, hygroscopic ability and low carbon emission. Consequently, the pinecone's natural strategies can be summarised as the adaptive mechanism, humidity and filtration control, fibres stretching, bending, wind-catcher structure, water drainage, growth and expansion.

4. Inspired Designs for Buildings

A unique roof was inspired by pinecone growth strategy which considers using a circular grid for the vents on the plan view to form expanded roof geometry. That design method divides the roof into three main parts (Figure 2). The humidity control strategy applies in part one. Forming the highest dynamic surface in the building where the adaptive mechanism of pinecone s has turned the roof into a natural humidity sensor activated by the humidity rate in the surrounding environment. Woody vents with high humidity sensors insulated by rock wool at the edges and fixed on a circular grid frames are used in this part. That matched Menges' research about controlling the smart lattice shell where vents open in humid low conditions to access light and provide natural ventilation. That pushes the building to the comfort level while adding a new design strategy to passive methods. In such a hot region, efficient application of passive ventilation will need a cooling process, balanced with indoor temperatures for better satisfaction levels. A pipe system with cold water will be used under the roof frames (Figure 3) to mitigate the entered air, the same as a pinecone's pockets. Furthermore, the application of rain drainage strategy can be clearly seen in the elevation view of the designed roof. Part one has a conical sloped shape while parts two and three slope in different directions. The integration of several slope directions helps to channel, harvest and store rain water to presenting grey water recycling process can be used in the cooling system, irrigation, or even flushing toilets to reduces the building's water consumption.

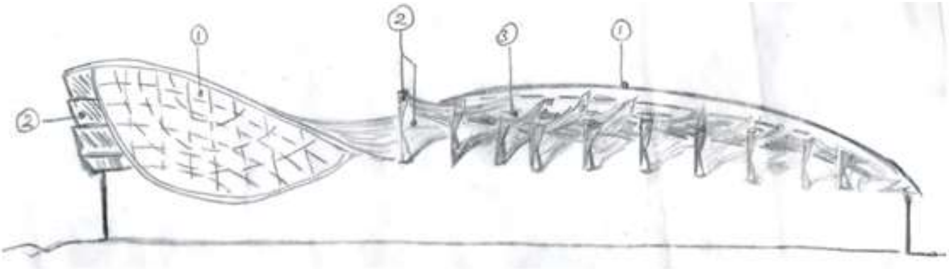

Fig. 2: An elevation view of the new inspired roof shows its three main parts. (Source: Author).

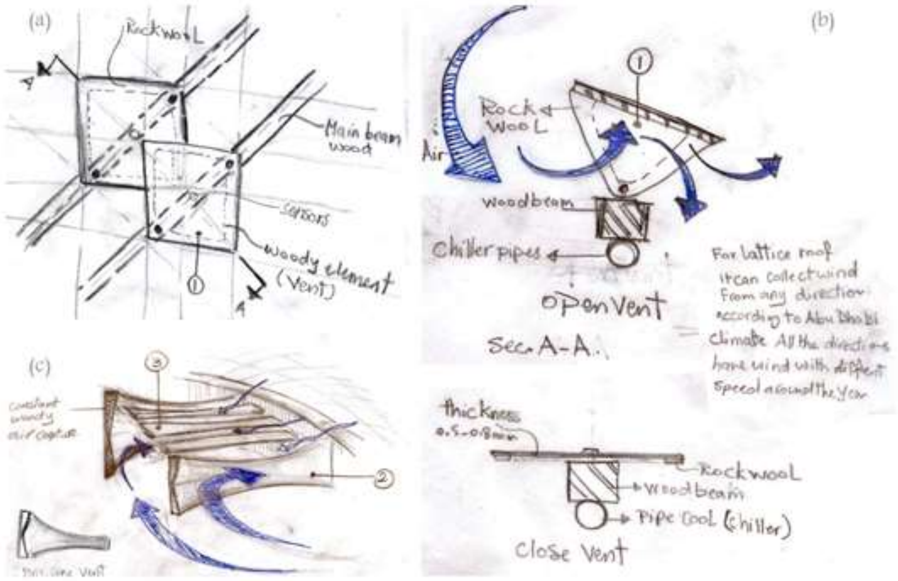

Fig. 3: Inspired roof's details. (a) Plan view of the dynamic woody elements- part no.1. (b) A cross section of the woody element in open and close conditions. (c) Pinecone vents as constant wind catcher – part no.2, and the sensitive lovers- part no. 3. (Source: Author).

In such a hot region, sand wind is the main concern when using a passive ventilation process. An inspired strategy can present solution by applying a filtration layer for the incoming air which imitates the internal constant layer of pinecone s vents protecting core from dirt. Otherwise, the ability of the roof to access daylight and ventilate in its open condition will require the use of a transparent flexible, hygroscopic material under the entire roof. Here Aerogel is recommended as an internal layer, Ramakrishnanet.al. (2008) describe Silica Aerogel as an extra coating material that has low density (0.003-0.55 gm/cm^3), low thermal conductivity (0.017 W/m.k), high porosity (99.8%) with transparency and a low reflective index.

Part two (Figure 2 and 3) is a constant wind-catcher which has the same angle and slope shape of pinecone vents. The specific central angle of the vent helps to collect the highest amount of air. Ten woody vents are designed in the new roof, sloping from the north elevation and rise up in the building's center while three other vents are fixed on the south elevation. The steps order of vents helps to distribute air, improve cross ventilation and provide shade for the north, south and west elevations. Part three shows the woody sensitive louvers distributing air and entering natural daylight (Figure 3).

5. Analysis and Discussion

The new inspired roof in figure 4 is evaluated in comparison with a proposed building in Abu Dhabi using the common roof materials examined on ECOTEC to highlight lighting and thermal performance. A distinctive lighting performance is presented in Figure 5. As is a common design concern in Abu Dhabi the south elevation is the highest collector of solar radiation which increases the building heat gain. On the other hand, in the same location, orientation and time the new roof worked well in distributing the solar radiation and protecting the south elevation.

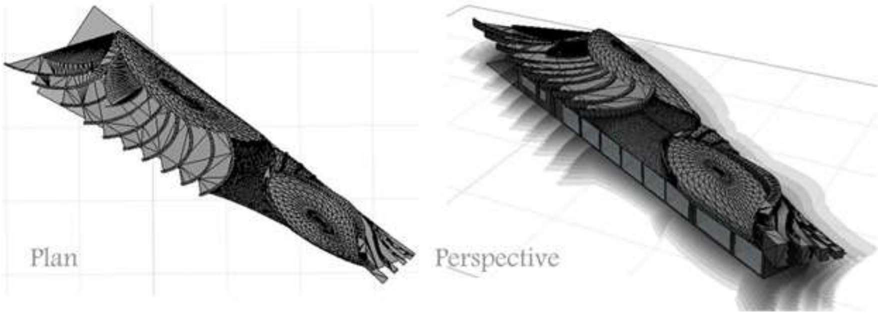

Fig. 4: Plan and perspective for the new inspired roof. (Source: Author).

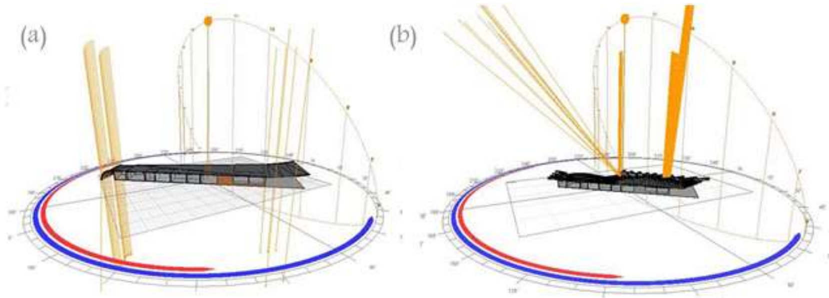

Fig. 5: Roof performance in reflecting solar radiation. (a) Original roof. (b) New inspired roof. (Ecotec Analysis 2011).

The original roof is comprised of five layers: interior plaster, concrete, bitumen, cement and exterior plaster, respectively while it has a U-value of 2.3710 W/m².k (Ecotec Analysis 2011). The main concern of such a building in Abu Dhabi is heat gain. Figure 6 presents material conduction at the highest average in summer as 37.7%. The main role of the roof in protecting the building from solar radiation shows another limitation of the original design where roof ability to resist heating is low at only 7.4% for solar air. The previous points explore the main reasons for increasing the internal heat in that building to 48.9% in summer. It is also necessary to highlight that heat loss in winter recorded as 51.1%. More Ecotec calculations show an unsatisfactory user level, fluctuating between 3.10 and 3PMV. That overheating problem led to use a full air conditioning system in order to provide internal thermal comfort, but disadvantages appeared in increasing the building’s energy consumption. Figure 7 shows that the cooling load in summer reached more than 8000000W, while its value for heating purposes in winter can be negligible.

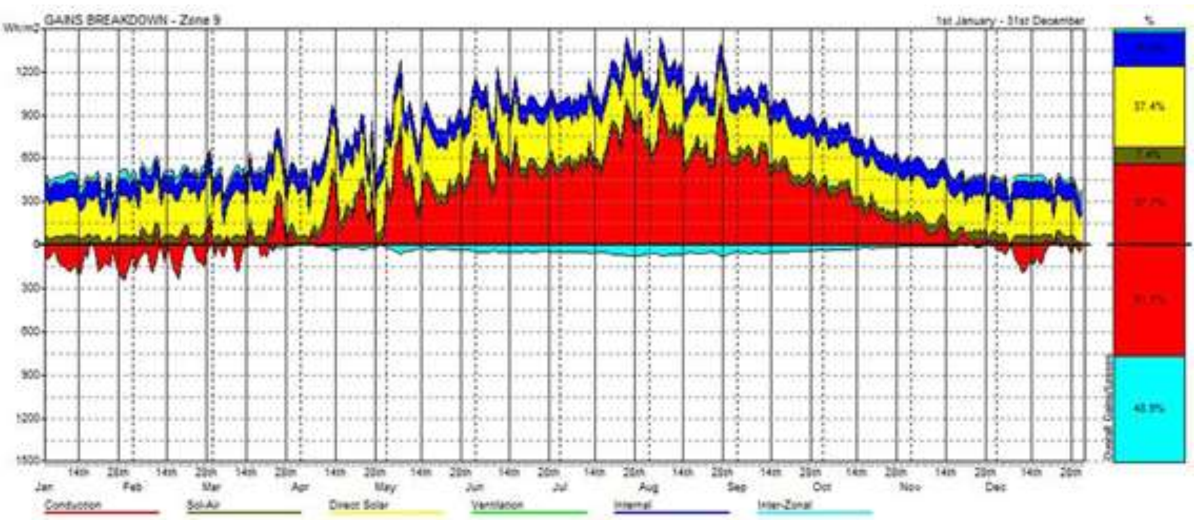

Fig. 6: Original roof – heat gain and loss analysis. (Ecotec Analysis 2011).

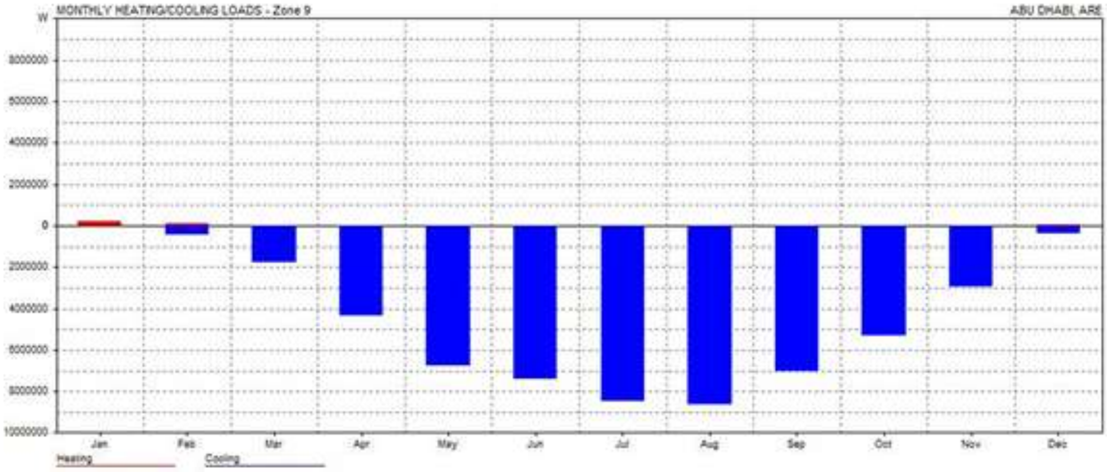

Fig. 7: Original roof – heat and cooling load analysis. (Ecotec Analysis 2011).

The new roof layer sandwich includes two timber layers for external and internal surfaces, two rock wool layers, two rubber silicon layers and a central air gap ordering from outer surfaces to the center. That presented a low conductive and highly resistant roof with only 0.610 W/m².k of U-value, which is about 25% lower than the first condition. Figure 8 records the new roof's heat gain and loss over the year. In contrast with the original condition, the new materials conduction level in summer is 21.9% which is lower than the old materials by 15.8%, considered being a huge difference. The new roof in winter is double effective than the original condition in terms of reducing heat loss. In addition, the solar air of the new roof is recorded as highly thermal resistant at 11.9%. Consequently, the high resistance levels of the new roof reduce the internal heat gain to only 7% which is lower - by about 41.9% - than the original condition.

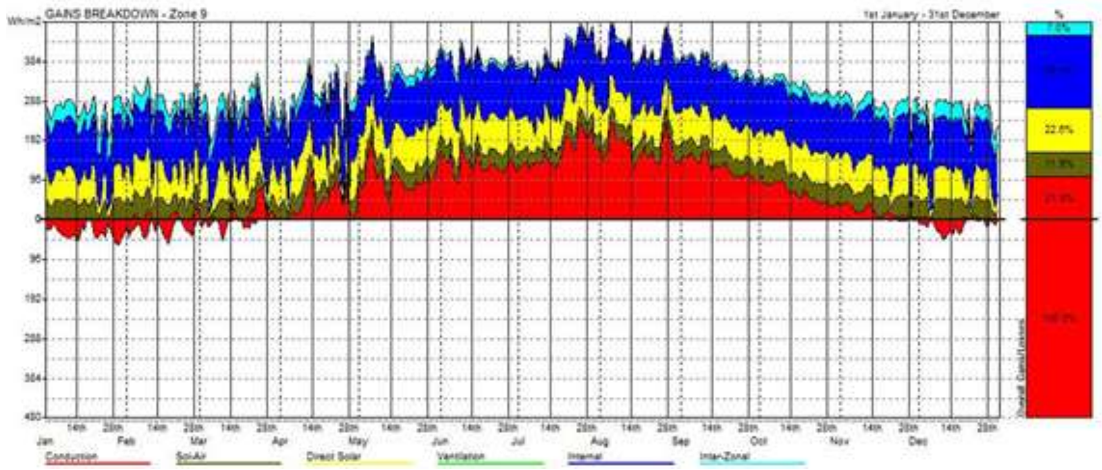

Fig. 8: New inspired roof – heat gain and loss analysis. (Ecotec Analysis 2011).

Ecotec calculation records a perfect indoor thermal comfort level under the new roof design, fluctuates between 0.5 and 0.6 PMV which is more comfortable for users than the first condition. That highlighted thermal comfort differences between both designs of about 20%. Figure 9 examines the new cooling system which looks like a chiller system for cooling water, but is considered also as a hybrid system integrates mechanical and natural ventilation together in one system. The figure shows that energy consumption of the building under the new design is only 3000000W which is lower by about 38% than the first condition. In addition, the figure did not present any records for the heating load, even at higher temperature differences between outside and inside in winter, because the efficient material's resistance in controlling heat loss in winter is high which maintains the building's thermal comfort level constant while removing the needs of heating system.

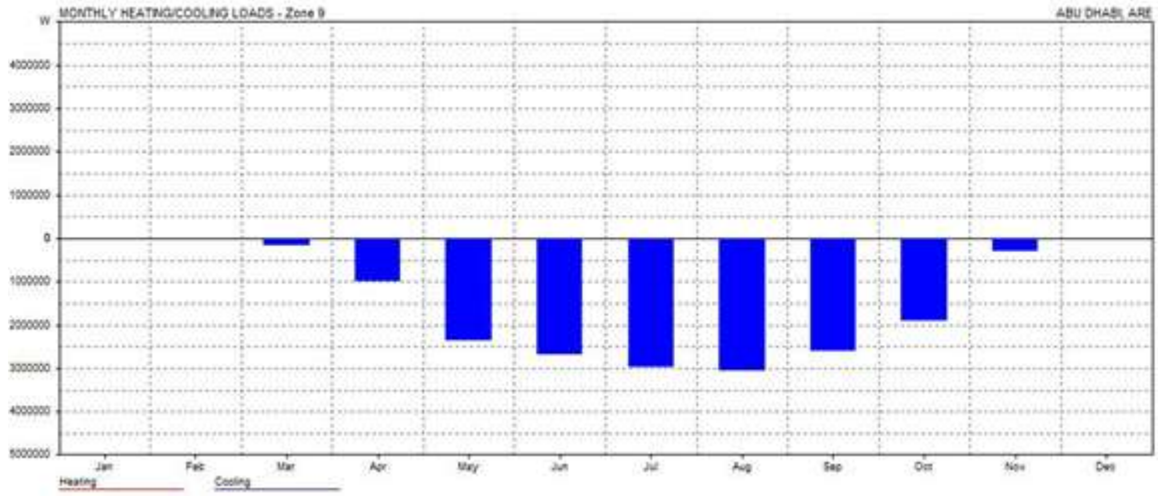

Fig.9: New inspired roof – heat and cooling load analysis. (Ecotec Analysis 2011).

6. Conclusion

In conclusion, the project aimed to find efficient ways to apply natural design strategies in improving building performance. The study analysed anatomy and behaviour of the pinecone while extracting eight main strategies which reflected latter in designing a responsive dynamic roof. A comparison between the performance of the original roof for a selected building in Abu Dhabi and the new roof was built on Ecotec. The findings highlighted the distinctive nature of the new roof in reflecting and distributing solar radiation to protect the south elevation. Reducing building heat gain by 41.9% from the original roof design which directly reflected on user satisfaction levels and building energy consumption to save about 38% of the energy. Finally, the study succeeded in integrating Biomimicry science in finding solutions for the construction field and enhancing building design for better performance.

7. References

[1] D. Baumeister, R. Tocke, J. Dwyer, S. Ritter and J. Benyus. *Biomimicry Resources Handbook- Life Principles, 1st ed*, USA: Biomimicry 3.8, 2013.

[2] Biomimicry Institute. (2011). Natural Humidity Sensors. *Ask Nature* [online]. Available: http://www.asknature.org/

[3] M. Hensel, A. Menges and M. Weinstock.Techniques and Technologies in Morphogenetic Design.Wiley, 2006, vol.76 (2), pp 81-82. England: Architectural Design.

[4] M. Hensel, A. Menges. Versatility and Vicissitude: Performance in Morpho-Ecological Design. Wiley, 2008, vol 78(2), pp 39-41. England: Architectural Design.

[5] A. Menges. (2009). Differenced wood lattice shell. *Per formative Wood Studio* [online]. Available: http://www.achimmenges.net

[6] E. Reyssat and L. Mahadevan. (2009). Hygromorphs: from pinecone s to biomimetic bilayers. *Journal of the Royal Society Interface* [online]. Vol.1. Available: http://rsif.royalsocietypublishing.org/subscriptions http://dx.doi.org/10.1098/rsif.2009.0184

[7] K. Ramakrishnan, A. Krishnan, V. Shankar, I. Srivastava, A. Singh and R. Radha. (2008). Modern Aerogels. *National Institute of Technology Calicut* [online]. 1(55), pp. 1-24 Available: http://ebookbrowsee.net

[8] Science Photo Library (SPL).(2012). Pinecone s Anatomy *Science Photo* [online]. Available: http://www.sciencephoto.com/

[9] C. Schittich, W. Lang and R. Krppner. *In Derail Building Skins New Enlarged Edition*. Germany: Institute for International Architecture- Documentation, 2006. http://dx.doi.org/10.11129/detail.9783034615082