SCIRES it
SCIentific RESearch and Information Technology
Ricerca Scientifica e Tecnologie dell'Informazione
Vol 5, Issue 1 (2015), 115-120
e-ISSN 2239-4303, DOI 10.2423/i22394303v5n1p115

SPACE AND ENERGY: RELATIONSHIPS AMONG ARCHITECTS FROM NATURE

Silvia Titotto, Daniel Oliveira**, Annarita Ferrante****

* Department of Aerospace Engineering – Center of Engineering, Modelling and Applied Social Sciences – Universidade Federal do ABC – Santo Andre, Brazil;
** Department of Architecture – Institute of Exact Sciences and Technology – Universidade Paulista – Sao Paulo, Brazil
*** Department of Architecture – University of Bologna – Bologna, Italy.

Abstract

This research reflects on the possibility of architecture eco-sustainable development from the point of view of energy, space and environmental heritage, based on the constructive process of some species of social wasps (*Hymenoptera*) and termites (*Isoptera*). It aimed at understanding via computational modelling and physical prototipation how their spacial design is developed by the "architect-insects" while they build their nests in nature as a way of preserving their bio-cultural heritage besides exploring other possibilites of eco-sustainable technological innovation within low energy consumption. The present work has been made to complement and converge the researches made both in the biomimicry area and the energy field by presenting how one can adapt the solutions in the built space of wasp nests and termite mounds that can be used in many ways at human constructions. Departing from some remarkable work done by entomologists, biologists and engineers, it was possible to get to structural details and how these tiny creatures build their dwellings little by little while they work as a united civilization. After getting to these details, strenghts and weaknesses were reported and one searched similar architectural human solutions for topics such as the crafting work on the surface of the buildings, the ventilation system created by the termites and the improvement of living spaces. By following the life of these little creatures and seeing how they can behave similarly to a human society up to an extent, one notes that one might learn and find architectural solutions by better understanding wasps and termites form-function challenges.

Keywords

Conceptual design, models, prototypes, functional morphology, biomimetic devices, installations

1. *Introduction*

Nature is probably the broadest source of inspiration that one could ever have and animals such as the insects might be considered their greatest architects. Most of them build their nests to serve them as a multitask shelter where they are born, they grow up, reproduce and die as their societies are started, based and inter-helped within those shelters.

The present work complements studies and works made in this area, raising questions about developing the art of designing and building somehow the way animals do. It also brings up the importance of thermal insulation of their nests as a broad source of case studies and it seeks comparisons among selected insects nests based on the analysis parameters of those nests, followed by the boldness of positive and negative aspects. Once reached the main research objective, it will be expected to facilitate further access to cutting edge ideas of how to design buildings based on the constructive process of insects and inspiring human architectural solutions from those nests. It is expected those solutions might be used as basis for application to human constructions in accordance to biomimicry processes.

In this way the authors aimed to produce pictures and then interprete 2D images so that 3D models could be designed for later prototyping the nests within their environmental context. Learning from wasps and termites form-function challenges might be a feasible way to approach the architectural development made by insects as a way of enhancing their biocultural heritage.

2. *Wasps*

2.1 Study of wasps for architectural purposes

Wasps are insects belonging to the order of the *Hymenoptera* that are the invertebrates responsible for pollination of several plant species. There are 974 species of social wasps in the world, and 304 of the 552 species found in the Americas can be found in Brazil (Carpenter & Marques, 2001). The social wasps, the ones studied in this work, belong to three of their total six subfamilies: *Stenogastrinae*, *Vespinae* and *Polistinae*.

The subfamily Polistinae stands out among the social wasps presenting species all over the world, with greater diversification occurring in neotropical regions, mainly in Brazil, where there are records of 26 genera described by Carpenter and Marques in 2001 and by Prezoto and Clemente in 2010. They are known as "paperwasps" according to Wenzel.

2.2 Nests

The foundation of the nests can occur either by independent foundation or by swarming.

In the first case, one or two queens start building the nest. They build the first cells and after the emergence of the first adults, they dedicate themselves only for ovoposition. The other adults will produce more cells and the protection for the colony. Although there will be other fertile females meeting the colony, only the queen has the egg laying function. Using his aggressive behavior does not allow other egg-laying females, and if any do, the queen protects his territory with physical aggression and ingestion of eggs that are not suitable.

In the second case, one or more queens leave an established nest and found a new colony. The workers looking for a new more appropriate place to start the colony and draw a pheromone trail on the way from the nest that is ready until the new location by rubbing an abdominal gland on prominent leaves so leaving their odor.

Polistinae nests are diverse. They range from a single honeycomb with about 5cm in diameter and a few dozen cells, to over 50cm in length and they can remain active for years, envelope millions of cells and covered by a "cover" called envelope, casing or wrapper (Carpenter & Marques, 2001).

They can be constructed of many different types of materials, such as vegetable fibers and trichomes of plants, which are macerated and mixed with water and, in some cases, secretion and granular clay (Wenzel, 1998).

2.3 Positive aspects

The shape of the nests is always changing according to the species of wasp. Social wasps normally use vegetable material to make the nest, but some species use clay – normally the solitary ones. With this difference between the materials, they never make nests with the same standard shape.

Some of them are structured by the bottom of leafs, others by a pedicel (Prezoto & Clemente 2010).

Always working together, wasps get many different shapes when they do the finishing, creating shapes and external styles that will always be recognized by their characteristics.

The process of construction of the envelope can involve many of the members of the colony, and for that reason the tonality of the material used by each individual is never the same, resulting in interesting differences, as in the Fig. 1.

Fig. 1: Different tonalities

The abundance of their circulation systems, as pointed out by the authors (Titotto *et al*., 2015) is also an aspect that is mainly positive, as it may be visualized in the Fig. 2.

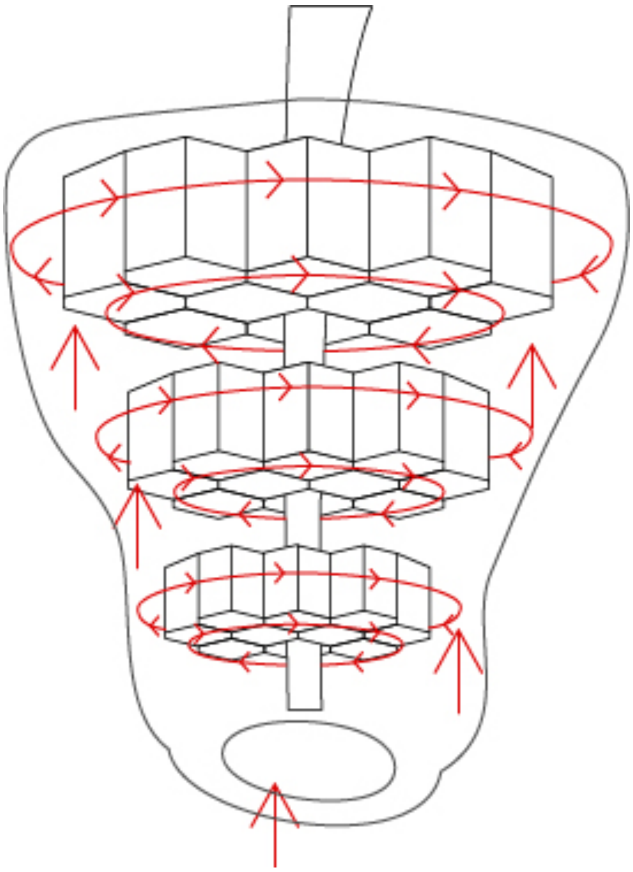

Fig. 2: Sum up of wasps circulation systems

2.4 Negative aspects

Although being one of the best positive points, the "abuse" of the quantity of circulation systems, it makes the wasp nests with a minor proportion of internal living space.

The entrances of the nest are always smaller than they should be, considering the high flux of circulation that happens in huge colonies.

3. Termites

3.1 Study of termites for architectural purposes

Termites, just like some species of wasps are social insects, but they belong to the Isoptera order. Known as "wood pests", they also call attention for their incredible social system inside their mounds.

In adittion to considerable economic damages in urban and rural areas, these insects are also important components to the fauna of tropical regions, decomposing and recycling nutrients.

There are four families in Brazil: the first one is the *Kalotermitidae*, considered the primitive termites; they live in dry woods and never get in touch with the earth, *Rhinotermitidae*, *Serritermitidae* e *Termitidae*. The second one is the Rhinotermidae, some of them are important pests and they feed up of wood. The third one is the *Serritermitidae*, containing only one kind of specie (*Serritermes serrifer*) occurring in Brazil. The fourth one is the Termitidae; they are altogether almost 85% of all the known species of termites in Brazil.

Most of them are feed up with wood and leafs, as the ones that are feed up with fungus do not occur in Brazil. Most of them build great and complex mounds. Inside the colonies, the termites are divided in castes, the soldiers, the workers and the king and queen. The King and the queen deal with the production of eggs, the workers do the entire repair and the construction of the mound and feed the other castes while the soldier defends the mound (Constantino, 1999).

3.2 Nests

The zimbabue termites build huge mounds. The mound is constructed out of a mixture of soil, termite saliva and dung. Termites do not live throughout the mound but spend most of their time in a nest located at or below ground level. They also cultivate fungal gardens, located inside the main nest area. Some say that these fungus must be keeped at exact 30.55°C, even with the outside temperature reaching from 1.6°C during the night to 40°C during the day, but according to Turner it is not something that can be affirmed. All that is known is that they are always opening and closing the ventilation tunnel rede, for heating and cooling. Turner also explains about two ventilation systems that could be what happens in the termites' mounds.

The first is the thermosiphon mechanism by Martin Loscherish that works in a continuous way. The heat of the colony (roughly 100 watts) imparts a sufficient buoyancy that the air of the nest can go up through the mound and drive to the top area, where it exchanges gases with the atmosphere across the porous walls, being refreshed. The higher density of this new-refreshed air forces it down again through the open spaces refreshing them (Fig. 3).

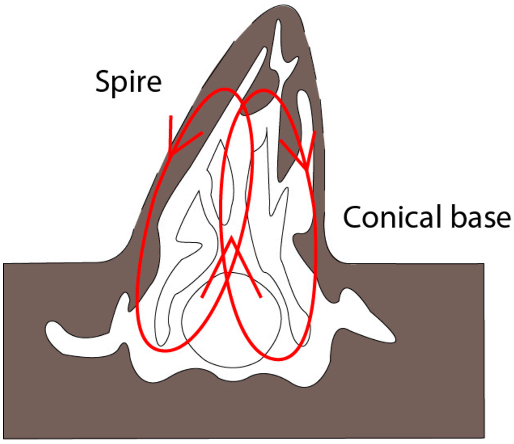

Fig. 3: Airflow

The second is known as "induced flow" to biologists or "stack effect" to engineers and architects. It occurs only in open chimneys mounds. The large chimney vent is exposed to higher wind velociteies than the openings closer to the ground. Unlike the thermosiphon, induced flow is unidirectional because the air is pushed by the small openings near to the ground and goes through the nest to finally get out through the chimney (Turner & Soar, 2008) (Fig. 4).

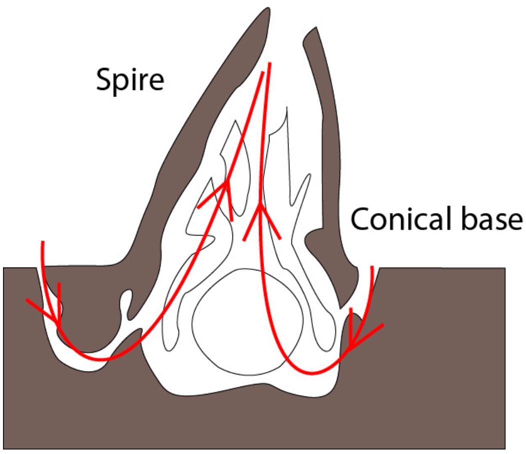

Fig. 4: Induced flow or stack effect

3.3 Positive aspects

The shape of the mounds is very interesting. The central tower remembers the verticalização as the many buildings that we see in the big cities. In one of his phrases, Turner compares the ventilation system of the mounds with our lung:

> "*When we breathe, we use the muscles around our lungs to push carbon dioxide out and draw oxygen in. By doing this, we preserve a delicate balance of temperature and moisture deep in our lungs. (...) We believe as a team we have found the same principle in termite mounds in Namibia, except instead of using muscles to breathe, the termites construct a mound which uses the complex energy in turbulent wind to do the same thing.*"

Following this system, termites are capable of keeping the mound temperature stable to store fungus. Some studies are trying to adapt this structure to make a new system of ventilation to be used in mines.

3.4 Negative aspects

Despite a magnificent structure and such a complex system, termite nests do not have nice appearance. Its material, the earth is a difficult material to make a good finish (Barthelat, 2007).

4. Biomimetization

4.1 Problem solving

The space is limited when there are so many circulation systems as it is in the wasp nests. The solution might be the one pointed out by the authors (Titotto *et al*., 2015): the less circulation system, the more living space (Fig. 5).

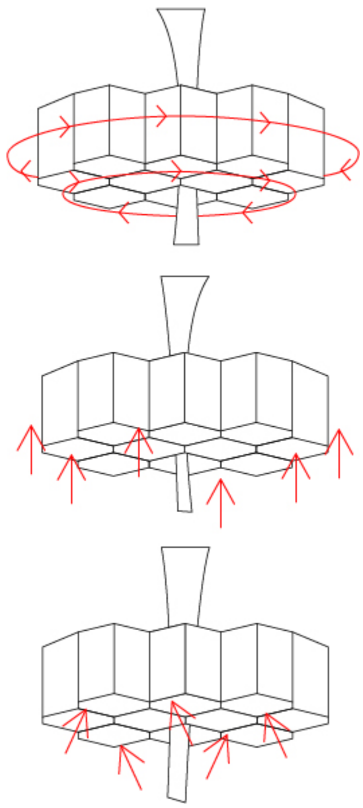

Fig. 5: The less circulation system, the more living space

There are at least two possibilities of solutions for the small entrances: in the first one, the conception of more than just one entrance, or maybe a hole for coming in and a hole for going out, similar to exits (Fig. 6).

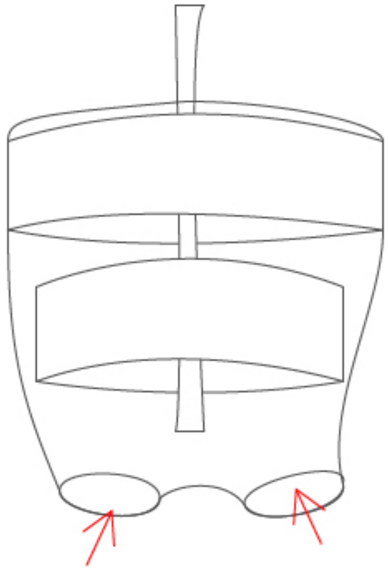

Fig. 6: Multiple entrances

In the second option, it might be possible to make a wider entrance (if there is just one entrance). In this case, the nest would be defenseless so this solution would only be applied if the nest were located in a very safe area (Fig. 7).

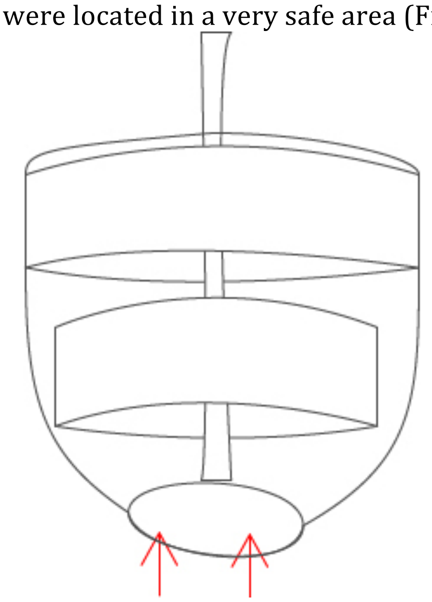

Fig. 7: A main entrance

Resulting from the comparison among nests of waps and termites, two sheets were created. Based on Ferrante (2013), they compare weight, width and diameter as welkl as material, structure and termal regulation between wasps and termites so that their architectural solutions concerning space and energy could be evaluated.

Tab. 1: Nests comparison

Wasps			
	Higher	Average	Lower
Height	Up to 2 Meters	20 Centimeters	Less than 5 Centimeters
Width	1.5 Meters	10 Centimeters	2 Centimeters
Diameter	2 Meters	12 Centimeters	5 centimeters
Material	Little fibers of wood mixed with saliva and water.		
Structure	Below or above leaves, or fixed in a pedicel.		
Termoregulation system	When it's hot, the workers throw water in the envelope.		

Termites			
	Higher	Average	Lower
Height	9 meters (spire)	3 meters (spire) 1.5 meters (conical	
Width			
Diameter		4-5 Meters	
Material	Barro		
Structure	Many little tunnels undergournd and normally a central chimney.		
Termoregulation system	Thermophison or induced flow.		

5. Final considerations

Biomimicry is the art that is inspired by the nature and make solutions for man problems. When we thing about solutions for the problems of nature, we can use that solutions to solve our problems.

This paper sought to bring out innovative thoughts from both old questions of learning with nature, as well as pioneering reflections from the latest research in biomimetic architecture and it sought to open the discussion about solving the problems of nature shelters and translating these solutions to human shelters and dwellings. However, it is important to acknowledge the limitations of translations and transitions between ecosystems, as pointed out by Titotto in 2013.

According to the main ambitions of this present research to serve as a complementary and subsidiary path to ongoing researches conducted in this interdisciplinary field, by the time one succeeds in the completion of these goals, it will be expected that researchers will have access to new perspectives of solutions based on the nests of wasps and termites that can be adapted to solutions for human constructions.

6. Acknowledgement

The authors express sincere gratitude to the members of the Brazilian research group “Estruturas Biomiméticas” for helpful discussions.

REFERENCES

Barthelat, F. (2007). Biomimetics for next generation materials. *Phil. Trans. R. Soc. A*, 365.

Carpenter, J. & Marques, O. (2001). *Contribuição ao estudo de vespídeos do Brasil (Insecta, Hymenoptera, Vespoidea, Vespidae)*. Universidade Federal da Bahia, Versão 1.0 – 2001, Série: Publicações digitais – Volume 2.

Constantino, R. (1999.) *Papéis avulsos de zoologia*. Museu de zoologia da Universidade de São Paulo, 40(25): 387-448.

D'Arcy Thompson, W. (2011). *On Growth and Form*. New York: Create Space Independent Publishing Platform (reedition from 1942).

Ferrante, A. (2006). *La città a pezzi o i pezzi di città nella costruzione sostenibile dei luoghi urbani*. Bologna: Oasi Alberto Perdisa.

Ferrante, A. (2013). *AAA Adeguamento, adattabilità, architettura. Teorie e metodi per la riqualificazione architettonica, energetica ed ambientale del patrimonio edilizio esistente*. Bologna: Mondadori Bruno.

Oliveira, D. & Titotto, S. (2015) Biomimetic analysis of Hymenoptera wasp nests. *J. Civil Eng. Architect. Res*, 2 (7).

Prezoto, F. & Clemente, M. (2010). Vespas sociais do Parque Estadual do Ibitipoca, Minas Gerais, Brasil. *MG. BIOTA,* 3 (4).

Rabello, Y. (2000). *A concepção estrutural e a arquitetura*. Sao Paulo: Zigurate.

Somavilla, A., Oliveira, M. & Silveira, O. (2012). Guia de Identificação dos Ninhos de Vespas Sociais (Hymenoptera, Vespidade, Polistinae) na Reserva Ducke, Manaus, Amazonas, Brasil. *Revista Brasileira de Entomologia*, 56(4), 405-414.

Titotto, S. (2013). *Branching morphogenesis: from growth patterns of vascular networks to biomimicry devices*. PhD Thesis, University of Sao Paulo & Politecnico di Torino.

Torres, V., Antonialli Junior, W. & Giannotti, E. (2009). Divisão de trabalho em colônias da vespa social neotropical Polistes canadensis canadensis Linnaeus (Hymenoptera, Vespidae). *Revista Brasileira de Entomologia*, 53(4), 593–599.

Turner, J. & Soar, R. (2008). Beyond biomimicry: What termites can tell us about realizing the living building. In *First International Conference on Industrialized, Intelligent Construction (I3CON)* (pp. 14-16). Loughborough University.

Vincent, J. (2006). Biomimetics: its practice and theory. *J. R. Soc. Interface*, 3.

Wenzel, J.W. (1998). *A generic key to the nests of Hornets, Yellowjackets, and Paper Wasps Worldwide (Vespidae: Vespinae, Polistinae)*. American Museum of Natural History, Number 3224, 39pp.