Contribution of Biomimetics for the development of Eco-neighbourhoods

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The world continues to face the problematic question of sustainability. Urbanism is one of the main challenges due the huge consumption of resources and significant environmental impacts as the percentage of world population that inhabits urban areas increases. The present research focuses on two concepts, eco-neighbourhood and biomimetics, aimed at improving the levels of sustainability in urban areas and areas undergoing the process of urbanization. The main objective of this dissertation is to explore these concepts, identifying the major advantages and disadvantages, as well as the main challenges they face. Following this exploration it is assessed the potential contribution of biomimetics for the development of the concept of eco-neighbourhood. To allow this analysis it was developed an application based on two distinct approaches: the first involved the application of biomimetic principles to more general problems identified on eco-neighbourhoods; the second involved the application of one methodology developed in this study which return relevant biological phenomena for the establishment of analogies between the biological domain and engineering which enhance the creation of appropriate biomimetic solutions to solve more specific problems of eco-neighbourhoods. It was found that the concept of biomimetics has the potential to contribute for the development of eco-neighbourhoods, enabling the achieving of higher levels of efficiency and sustainability and the solving of its main challenges of better environmental and socio economic performance.

Key-words: biomimetics, eco-neighbourhood, urbanism, sustainability, relevant biological phenomena, analogy

1 Introduction

The world continues to face the problem of sustainability mainly due to the impacts of human civilization over the environment. It was established that unless significant changes are taken, the limits of growth of the planet will be reached with severe environmental, social and economical consequences (Meadows *et al.*, 1972). One of the most influential areas to those impacts is the concept of urbanism. As human civilization becomes an urban civilization, with more population living in urban areas day by day, those areas increase their intake of natural resources and their necessities increase continuously. With the increase in the inputs necessary to the operation of the urban areas, results the increase in negative impacts such as production of waste, emissions and the degradation of natural ecosystems. Urbanism is considered as a key aspect in the settlement of a sustainable development (The World Commission on Environment and Development, 1987).

The urbanism is a vast and ancient concept which accompanied the development of numerous civilizations since the Sumerian civilization. Using urban planning humans were able to establish their first villages in a symbiotic relation with the surrounding environment, enjoying the advantages of co-habitation and of the conditions provided by nature in the form of protection against predators and

the availability of natural resources such as water and food (Mumford, 1961). But urbanism changed significantly as humans got the technology, the resources, the man-power and the capability to create urban environments resistant to the unpredictability of Nature (Mumford, 1956). This capability created an increasingly disaffection between humanity and Nature, which is considered the root of all the environmental problems that still exist today (Mumford, 1961).

Urbanism faces severe and very complex problems that have been developing starting from the root mentioned before. The negligence of the social factor is one of those problems because it is considered in the majority of urban projects as the weakest link and because the responsible for the urban development do not understand the importance and the role of this factor (Mumford, 1937). Other problems faced are the suburban overspill, a problem that rises from a solution to escape from the fast rhythm of the city resulting in the invasion of land dedicated to the agricultural practice and natural sites by the urban veil (Mumford, 1956), and the conurbation, a concept that involves the coalescence of different urban areas in expansion (Geddes, 1915). It is important to mention two more important problems, the influence of different interests and the application of dysfunctional politics (Mumford, 1956), and the impossibility of new construction.

Many were the approaches in urbanism that aim to the resolution of these problems and the achieving of higher performances and lower environmental impacts. Such approaches as *garden-cities* (Howard, 1902), *polynucleated cities* (Mumford, 1937) and *urban metabolism* (Wolman, 1965) brought new potential for a change in urbanism. In this demand for higher environmental performance in urbanism arise the *Eco-neighbourhoods*.

As the concept of eco-neighbourhoods is developed and gathers around him more public, media and scientific attention, with the establishment of various projects primarily in the North of Europe (Souami, 2009), the advantages, disadvantages and the problems that constrain their success are identified and explored. Another concept that re-emerges timely is the *Biomimetics*. This concept coined to Otto Schmitt (Harkness, 2002) can contribute in this demand for sustainability with new creative solutions and more efficient processes and can be applied in the engineering. The main objective of this research is to explore and develop the concepts of eco-neighbourhood and biomimetics, and analyse the possible contribution of biomimetics in the development of the eco-neighbourhoods.

2 Eco-neighbourhoods

The eco-neighbourhood is a concept with great potential which aims to gradually transform the urbanism, focusing in the urban planning of neighbourhoods with the objective of obtain neighbourhoods more sustainable and responsible, marked by an improvement of the quality of life and a considerable utilization of recent environmental technologies. Boutaud (2009) define eco-neighbourhood as: *New space constructed or renewed of a city, inserted or near of a dense urban centre, at the scale of neighbourhood, with the objective of implement, preserve e develop through time all the environmental, social and economic principles inherent to sustainable development which ruled its planning and conception.*

2.1 Advantages, Disadvantages and Challenges

In this research the concept of eco-neighbourhood was explored in three different ways. First, the cases of some existing eco-neighbourhoods and their results were analysed to identify the major advantages and disadvantages, as well as the

success or failure of some measures. The cases studied were *BedZed* (United Kingdom), *Vauban* (Germany), *Hammarby Sjöstad* (Sweden), *Vesterbro* (Denmark) and *Eco-Viikki* (Finland) (Energie Cités; ADEME, 2008). Second, the eco-neighbourhood was deeply analysed through the concept of urban metabolism to identify major challenges faced. This concept coined to Wolman (1965) allows to approach the eco-neighbourhood as an urban ecosystem and to deconstruct it in different flows of inputs and outputs that form its metabolic process. The major flows considered were the water resources, the energy, food and materials (see Figure 1). Third, relevant critics were identified and explored to assemble the top disadvantages and flaws respective to the concept of eco-neighbourhood.

Through these three approaches there were identified many advantages, disadvantages and challenges or problems, some of them are presented next. *Advantages*: better environmental performances; potential to support a circular urban metabolism; higher levels of comfort and quality of life to the inhabitants; attraction of economic and touristic investments; and development of community and cooperative sense. *Disadvantages*: lack of clear definition; huge budgets and costs; weak commitment with the social factor; potential source of negative externalities to the remaining urban tissue; and overreliance on environmental technologies. *Challenges*: utilize residual waters efficiently towards circular urban metabolism; reduce the energetic consumptions without affecting the quality of life; reutilize waste towards circular urban metabolism; reduce costs; and proper insertion of the eco-neighbourhood in the remaining urban tissue.

2.2 Distinction between models of North and South of Europe

It is also important to identify a clear distinction between the projects implemented in the North of Europe and the projects still in development in the Southern Europe. The northern model is more focused in environmental performances and technology, while the possible southern model is more focused in social and economic factors (Souami, 2009) (Kyvelou & Papadopoulos, 2011). Verdaguer (2000) conclude that eco-neighbourhood is a modern and more sustainable version of Mediterranean towns.

Figure 1 – Urban metabolism of an eco-neighbourhood with the main flows of inputs/outputs

3 Biomimetics

Biomimetics is a concept with great potential and whose contribution can provide the capacity to achieve higher levels of efficiency and performance in engineering and other sciences. Concept coined to Schmitt who defined it as the observation of biological phenomena to gather inspiration and knowledge used to develop physical or bio-physical systems in the image of life (Harkness, 2002). This concept is based on the great potential of Nature to develop unique and very efficient organisms and mechanisms through millenniums of adaptation and evolution.

3.1 Advantages of biomimetics

Biomimetics has inherent a vast set of advantages related with many advantages observed in the biological world. Paturi (1976) refers the efficient use of resources. Bond *et al.* (1995) point the self-assembling capacity and precision of processes. Galbraith (1989) mentions the skill of adaptation and the operation through feedback cycles. French (1994) highlights the design oriented towards functionality. Benyus (1997) refer advantages such as the respect for life and for the remaining systems and organisms. Affholter and Arnold (1999) emphasize the operation of systems through a wide spectrum of conditions. Bar-Cohen (2006) enhances the multi-functional capacity and for last Vincent *et al.* (2006) highlight the hierarchical organization and the focus on the variables of information and form.

3.2 Biomimetic principles

From the observation of biological phenomena and respective key characteristics and advantages it is possible to identify a set of principles that rule life and all the mechanisms and processes involved in the biological domain. The biomimetic principles developed in this research are the following:

- Do more with fewer resources;
- Adaptation to external and internal changes;
- Design oriented to multi-functionality;
- Simplicity and composition;
- Operation through feedback cycles;
- Proximity and availability;
- Interconnectivity;
- Establishment of mutualisms.

3.3 Methodologies of application of biomimetics and difficulties

Biomimetics have been recently the target of some investigations with the aim of developing effective methodologies of application. These studies allowed the identification of several difficulties upon the application of biomimetics. The methodologies explored aim to facilitate the process of search of analogies in the biological domain and their applications (Vakili & Shu, 2001), the identification of biologically key-words to be used in the search of relevant biological phenomena (Cheong *et al.*, 2011), the effective transfer of analogies from the biological domain to the engineering (Cheong & Shu, 2009), and the development of compose analogical methods to apply the biomimetics (Vattam *et al.,* 2007).

Relatively to the problems and difficulties identified, Nagel and Stone (2011) appointed the difference existent between the engineering and the biological domain, more specifically the difference between the two thesauri used in each one, as one of the major problems faced in the application of biomimetics. Vakili and Shu (2001) highlight the importance of considering the functionality and not the flow during the search of biological phenomena. Thereby, the functionality can be the element able to approach and connect engineering and biology. Cheong and Shu (2009) refer as one of the difficulties the recognition of causal relationships in biological descriptions. These causal relationships are essential to correctly understand the description, and thus the mechanisms involved in the biological phenomena.

4 Developed methodology

In this research it was developed a methodology that aims to facilitate the application of biomimetics to problems faced in engineering, based in an organized set of steps which allow the correct use of the potential of biomimetics. Those steps will be exposed next and aid in the search of relevant biological phenomena, the proper understanding of the mechanisms and processes involved and the establishment of analogies able to inspire innovative solutions.

Problem definition

A proper problem definition is a key step for the successful application of biomimetics. Problems

defined way too simple or badly understood tend to originate inadequate and ineffective solutions. The correct definition depends upon a right understanding of the problem, utilizing a certain degree of abstraction.

Problem decomposition into sub-problems

Problem decomposition is a method that allows understanding thoroughly the problem at issue and its simplification through the split of the problem into smaller problems (sub-problems) which have attached to them more specific functionalities.

Identification of the functionalities respective to each sub-problem established

A problem can be defined as a specific undesirable situation whose solution involves the achievement of some functions under a certain set of conditions or limitations. In this step one must proceed to the identification of: functionalities desired for each sub-problem; *modus operandi* of their achievement in engineering; conditions to be fulfilled; limitations to be considered.

Identification of relevant functional words for each functionality established

Functional words are words belonging to the functional basis of engineering aimed to establish a standard representation of the major functionalities desired in engineering. Making use of researches such as the one elaborated by Hirtz *et al.* (2002), in this step one must proceed to the identification of the functional words that best represent the functionalities identified in the previous step.

Translation of the functional words established into biologically meaningful keywords and identification of other similar keywords

In this step the objective is to identify biologically meaningful keywords which can be used to search the biological domain for relevant biological phenomena for the problem in question. First, one must proceed to the translation of the functional words set previously into biologically meaningful keywords making use of the process of translation developed by Cheong *et al.* (2011). In that study the researchers develop a process that results in a table where each functional word has a corresponding set of biologically meaningful keywords. Second, on must identify other biologically meaningful keywords not identified by the process presented above, but which can facilitate the search of pertinent biological phenomena.

Selection of the initial source of biological information

The choice of the initial source of biological information is also a very important step. This first source must not be too specific, comprising several organizational levels of the biological domain which allow a vast variety of biological phenomena covered, and must not be too advance and complex, to facilitate the process of understanding to researchers without a biology background, such as engineers. It is suggested the use of introductory books to biology such as "*Life The Science of Biology*" (Sadava *et al.,* 2011).

Definition of an adequate bridge (approach) to support the search of biological domain

The bridge addressed in this step is the approach that enables the research of biological phenomena on the biological domain, facilitating and speeding up this process. An efficient bridge suggested in this study is computer based searches which relies on the availability of the source of biological information in digital format (*portable document format-pdf*). This bridge allows faster, complete and more effective searches.

Identification of relevant biological phenomena for each sub-problem and respective functionalities

The carried search will return several biological phenomena due to the biological meaningful keywords. The researcher must then select and keep the relevant phenomena and despise the inadequate

matches based on the respective descriptions and diagrams attached and considering the desired functionalities. If one is unable to understand the description presented, it is suggested the use of the following template on the description:

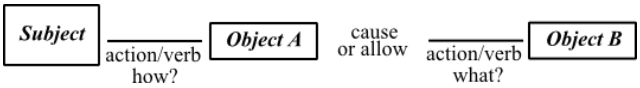

Figure 2 – Template to reformulate complex biological descriptions (adapted from Cheong & Shu, 2009)

Search of additional information on more advance and specific sources if necessary

If necessary one must in this step search for additional information on the relevant biological phenomena identified in the previous step. To support this new research it must be selected a new source, preferably in digital format as well to allow computer searches. Due to the higher levels of cognitive effort necessary to understand the complex descriptions on this advance source, it is suggested the strong consideration of diagrams and images attached. If necessary one can use the template presented above (see Figure 2).

Establishment of analogies to inspire new solution and/or more effective decompositions based on the knowledge gathered

In the last step of this methodology developed the knowledge gathered due to the researches on the biological domain are used to establish adequate analogies between engineering and biology, able to inspire creative new solutions that allow the achievement of the desired functionalities and consequently the resolution of the sub-problems addressed. Then one must integrate all the solutions obtained in a convenient and proper way. Of this integration results the composed solution for the main problem in question.

From the knowledge gathered it is also possible and advantageous to establish new approaches to the problem or sub-problems decompositions, since some biological phenomena also divide their main functions into smaller and easier functions to address their achievement. Thus one can use this possible information to perform more effective decompositions.

In Figure 3 it is exposed the overall methodology for a simple case and for a complex case, performing new decompositions based on the information gathered.

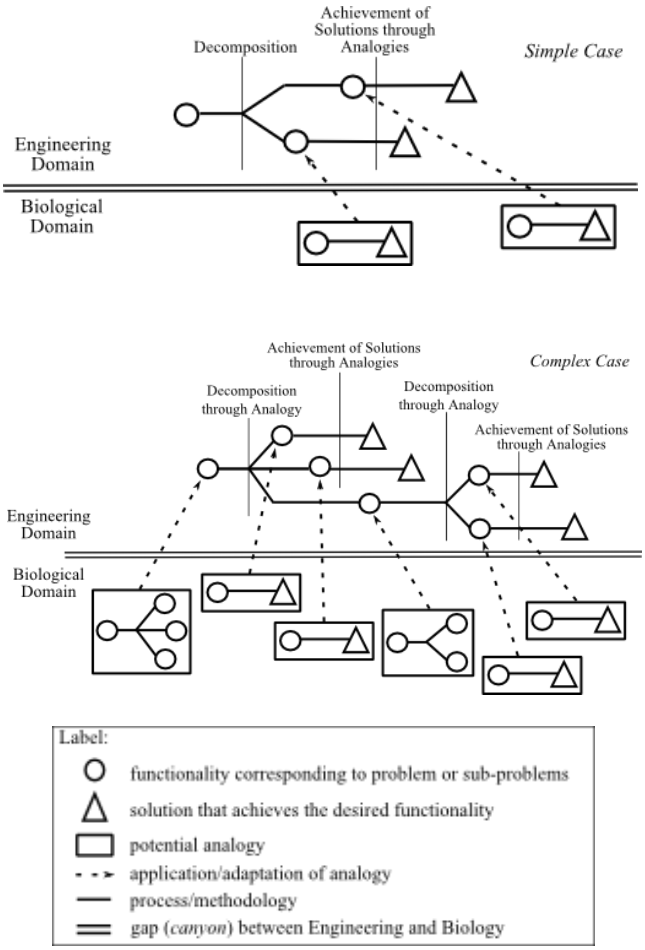

Figure 3 – Application of the developed methodology in a simple case (first) and in a complex case (second) (adapted from Vattam *et al.*, 2007)

5 Application of biomimetics to problems of the eco-neighbourhoods

The application of biomimetics to problems of the eco-neighbourhoods was accomplished in the present research through two distinct approaches, first by the application of the biomimetic principles to more general problems of eco-neighbourhoods, and second by the application of the conceptual

methodology developed before on more specific problems.

5.1 Application of the biomimetic principles

In the present research the biomimetic principles were applied to some more general problems identified in the concept of eco-neighbourhood to exemplify how they can be used to improve this concept and allow it to achieve better performances.

5.1.1 Proper insertion of the eco-neighbourhood in the remaining urban tissue

One of the major problems identified on the concept of eco-neighbourhood is the proper insertion in the remaining urban tissue. One possible approach to initiate the resolution of this problem could be the application of the biomimetic principle of the *Interconnectivity*.

This biomimetic principle of interconnectivity involves the establishment of relations between all the elements of the system in question, allowing the settlement of a flexible system that always aims for the best equilibrium. It can be applied to the problem mentioned previously by an approach aimed to the settlement and improvement of the external communication, thus creating new lines of communication which allows having feedback from the surrounding zones and neighbourhoods. Thereby, the negative externalities produced are known and can be addressed so that they can be cancelled or avoided.

5.1.2 Reduce costs of the eco-neighbourhood

The huge budgets and costs involved in the establishment of eco-neighbourhoods is another great problem that hinders the development of the concept and its vaster diffusion in urbanism.

A biomimetic principle that can be applied in this problem is for example the principle *Operation through feedback cycles*. A possible measure born from this principle is the utilization of the outputs produced by eco-neighbourhoods. As the majority of cases studied already use the material waste in alternative ways, reducing the quantities targeted to elimination, waste is still regarded as garbage. This biomimetic principle is based on the Nature's feature of regarding everything as resource. In Nature there is no such thing as waste. Applying this principle to eco-neighbourhood results in a change of treating the outputs produced. If eco-neighbourhoods develop ways to re-introduce the organic and inorganic waste, the residual waters and possibly the gas emissions into the urban metabolism it is possible to reduce the consumption of natural resources, increase the use of outputs as resources and thereby significantly reduce the costs.

5.2 Application of the developed methodology

In this part it is exposed the application of the methodology developed previously into a more specific problem of the eco-neighbourhood, namely the problem of energy efficiency in acclimatization of residences in the eco-neighbourhood. Following the steps of the methodology it was possible to gather some relevant biological phenomena that can be used to establish innovative solutions for this problem. Some of the data developed throughout the methodology is presented next to exemplify its use and potential.

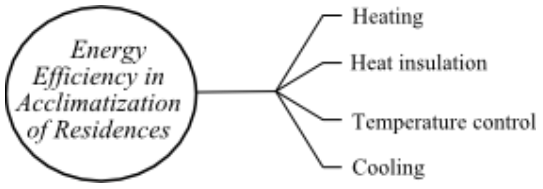

Figure 4 – Result of the steps involving problem definition and decomposition of problem into sub-problem

Table 1 – Identification of the functionalities corresponding to each sub-problem

Problem: ***energy efficiency in the acclimatization of residences***				
Sub-problems	**Heating**	**Heat insulation**	**Temperature control**	**Cooling**
Functionalities	Heat supply	Heat retention	Regulation	Heat extraction

Table 2 – Identification of relevant functional words respective to each functionality

Functionalities	**Heat supply**	**Heat retention**	**Regulation**	**Heat extraction**
Functional words	*Import Transmit Transfer Increase Collect Convert*	*Inhibit Store Contain*	*Signal Measure Regulate Change*	*Extract Export Transfer Transmit Decrease Inhibit*

Table 3 – Biologically meaningful keywords corresponding to each functional Word identified

Sub-problem: ***Heating***						
Functionality: ***Heat supply***						
Functional words	**Import**	**Transmit**	**Transfer**	**Increase**	**Collect**	**Convert**
Biologically meaningful keywords	Osmose Pass through Squeeze Diffuse	Contract Transduce	Conjugate Beat Transport	Stimulate Activate Contract Molt	Break down Convert	Degrade Stimulate Fuse Decompose

The next steps involve the selection of the initial source of information and the selection of the adequate bridge. The source of information chosen was the introductory book "*Life The Science of Biology*" by Sadava *et al. (*2011). The bridge was the computer search enabled by the availability of the book in digital format (*PDF*). The following step involves the search of relevant biological phenomena based on the biologically meaningful keywords identified. All the functionalities desired, even two more established by the decomposition of the functionality *Heat supply*, can be seen in Figure 5.

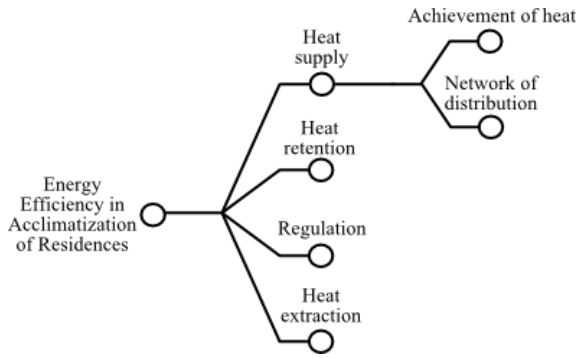

Figure 5 – Establishment of the desired functionalities

For the functionality *Network of distribution* and using the keyword *Diffuse* it was possible to identify, for example, the tracheal system of insects (see Figure 6). This biological phenomenon can be used to inspire new solutions in engineering for the effective and balanced distribution of heat into the residences, avoiding the significant difference among various rooms. The tracheal system of insects with its vast network and the spiracles distributed across it allows an efficient exchange of gases with the external environment all across the body of the insect, thereby allowing equilibrium of conditions such as temperature in all the parts of the insect.

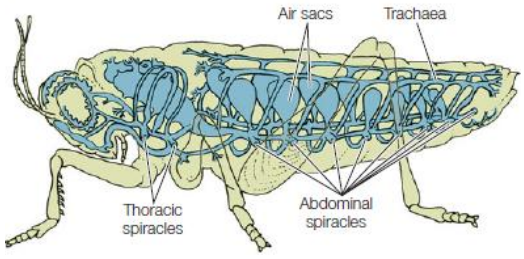

Figure 6 – Relevant biological phenomena identified: the trachael system of insects (Sadava *et al.*, 2011)

6 Sequence of application of biomimetics to an eco-neighbourhood

In order to facilitate and orient the application of biomimetics to an eco-neighbourhood it was developed a sequence or checklist that highlight all the important aspects and steps to have in account. This sequence is composed by the following steps:

- Identification of the physical features of the project;
- Environmental conditions framework;
- Social conditions framework;
- Economic conditions framework;
- Recognizing strongest and weakest aspects;
- Establishment of the desired goals;
- Study of the urban metabolism;
- Identification of problems;
- Application of biomimetics to problems;
- Integration of developed solutions;
- Monitoring of applied solutions;
- Identification of future biomimetic developments.

7 Conclusions

The main objective of this research was to analyse the potential contribute of biomimetics to the development of eco-neighbourhoods. Through the exploration of the concepts of eco-neighbourhood and biomimetics it was possible to indentify the advantages, disadvantages and major problems that each one faces.

Eco-neighbourhood is a concept with high potential to change the urbanism and achieve sustainability, but still somewhat incomplete due to a lack of a strict definition. They still have some important challenges to be solved towards higher levels of efficiency and quality of life.

The concept of biomimetics has also much potential to aid engineering and other sciences towards new and better solutions to complex problems that remain unsolved. Based on the observation of Nature, it relies on an unlimited source of unique and innovative biologic phenomena, which perfected along millenniums, developed extraordinaire mechanisms and features that can be used to establish analogies and inspire revolutionary solutions. Nevertheless, it is a relatively recent concept and methodologies to apply it correctly are still in development. In the present research it was established a methodology that can be used to adequately apply biomimetics and search the biological domain for relevant biological phenomena. The methodology reveals as well successful since it enables the identification of some pertinent biological phenomena with relevant features concerning the problem faced in the example.

Through the application of biomimetic principles and the application of the methodology developed it is possible to conclude that biomimetics can contribute positively to the development of eco-neighbourhoods, since it can provide inspiration to creative solutions able to solve the problems inherent to the concept of eco-neighbourhood. Those solutions are based on an unlimited number of possible analogies established between engineering and the vast domain of Nature.

The sequence briefly presented in the end allows an oriented and organized application of biomimetics to an entire eco-neighbourhood, which considers all the major aspects capable to influence the operation of an eco-neighbourhood and that need to be addressed before applying biomimetics. Through this there is the possibility of applying biomimetics in a traditional neighbourhood and harness the advantages of it.

8 Future developments

In future developments it is important to further develop the methodology of application here established, especially the process of identification of the biologically meaningful keywords and the search for biological phenomena. To further analyse the contribution of biomimetics to eco-neighbourhoods is necessary a complete application that covers all the problems and develop more detailed solutions.

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