Inspired by Nature: The Sun and Shadow Pavilion, Social Integration and Energy Saving in the Built Environment

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Abstract. The paper deals with the socially inclusive and energy-saving architectural forms in urban space. These forms are treated as an ecological event (eco-event) per analogies to Bernard Tschumi's concept "event city". According to this concept essence of space is to animate movement and actions, which strengthens the social and ecological or political dimension of architecture. In this way, an architectural object is a discourse on spaces and events that take place in it. The aim of the research is to present the possibility of using architectural forms as eco-events in the process of improving space quality and the microclimate prevailing in it. The aim of the research is to present the possibility of using architectural forms as eco-events in the process of improving space quality in the built environment. The first part describes the meaning of the term "eco-event" and provides selected examples in public space. This part analyses Biomimetics with its design strategies and methods. The Problem-Based Approach (designers look to nature for solutions) and the Solution-Based Approach (biological knowledge influences human design) are defined here. The second part presents the results of the research programme undertaken at West Pomeranian University of Technology in Szczecin by the authors of this research paper. The programme is focused on adaptive built environments and envisions new solutions based on advanced digital technology. The presented research is going to find ways to create the Nature-inspired architectural object (eco-event) for public use. This research study has resulted in a proposal for a solar-active pavilion as a discourse on the built environment and energy-efficient design principles. This study and design also highlight the problem of the modulation of micro-environmental conditions within an emergent macro-environmental system.

1. Introduction

Transforming today’s cities into sustainable eco-cities is one of the main adaptations that will be a necessary step forward. Ecological engineering and architectural design offer a holistic approach, a wide spectrum of possible solutions such as an idea named "eco-event in the city". In this concept, architecture has the ability to activate space by stimulating people to act and develop their knowledge as well as to implement urban ecology worldwide. Throughout the history, humankind has always interacted with nature, e.g. by learning something about life from life from it. This interaction is clearly manifested in the first shelters as well as in contemporary modern buildings. Architects have looked to nature for inspiration for building structures and methodologies [1]. They have been searching for answers to their complex questions about various kinds of shapes, structures or processes, and they have mimicked numerous forms from nature to create better and more efficient
structures for different architectural purposes. In addition, since the earliest time, man’s interaction with nature has created disruptive and damaging effects, either through the generation of energy, the creation of artificial landscapes, the construction of buildings, or soil cultivation [2]. These problems, which have become threats to our life standards have highlighted the importance of raising awareness. After the industrial revolution, the increasing population and the growing need for energy have led to the depletion of natural resources and necessitated the search for alternative solutions. This is when, eco-oriented design approaches have emerged.

The presented study is a practical application of the experimental approach to architectural and urban design in the recently re-opened discussion on the possibility and advisability of creating places of social integration, aimed at developing knowledge of urban ecology in the face of the consequences of global climate change.

2. The meaning of the term "eco-event" in architectural and urban design

Social networks and ubiquitous technologies have transformed the ways in which we communicate, learn, work, consume, express emotions, relate to each other, create and share information and knowledge. However, life goes on in the real world, not just virtual reality. For urban residents, this real realm is a city where various activities take place. All of these digital spaces do not manifest the characteristics of event space in the city, though. The term "'eco-event'" has emerged as a useful way to encapsulate the still somewhat fuzzy concepts of an ideal relationship between people, governance, built environment, infrastructure, living ecosystems, resource use (e.g. energy). In architectural and urban design, the term refers to Bernard Tschumi's concept of "event space" in the city. For Tschumi, space is "created" by an event taking place within it; and architectural space is defined by the activity taking place inside/in front/around – in any spatial relation with it [3]. The term has become commodified in recent years, and is now regularly applied to corporate various activities in public space with the use of architectural temporary or mobile objects. However, there is an interpretation of this concept; as a common ground or infrastructure, which can be freely used for a multitude of activities or functions. Nowadays, the experiment conducted by Tschumi in the Parc de la Villettehas entered a completely new phase. These structures are often a tool for manifesting ecological values and possibilities of new technologies in the urban landscape. Through their specific exhibitions and programme as, a sites for interaction and integration is created. This site can be called an "eco-event" in the city. Adding this specific urban element to the discussion, Lefevbre's phrase “the right to the city” [4] captures individuals' rights of access not only to physical public spaces, but also to the public spheres of discursive participation which should be enabled by such sites today.

2.1. "Eco-event" in public space - two examples

Epiphyte is a completely self-sufficient, modular summer pavilion, created to travel around the world providing its surrounding with a natural aesthetic, explaining modern and ecological building systems in one architectural experience (Figure 1).

Figure 1. Bart Bratke, Paul Clemens Bart, Marvin Bratke, Epiphyte Pavilion, 2000
The name of this pavilion refers to an organism that grows on the surface of a plant and derives its moisture and nutrients from the air, rain, water (in marine environments) or from debris accumulating around it. This pre-fabricated organism is designed to have carbon-zero emissions, collecting energy at daytime using it for media projection at night. It benefits from its green or urban surrounding, while providing a new and interesting space for exhibitions and art installations. The cladding of the structure is covered by a TiO$_2$ nano layer of shaped anatase that reacts to ultraviolet rays, enabling the reduction of air pollution and, cleaning the atmosphere around the pavilion. Epiphyte collects rainwater at the three lowest points of its construction, storing the grey water in a central core where it is filtrated, cleaned, vaporized and used by the mist system to cool down the surrounding, and the thin film photovoltaic cells on the roof of the summer pavilion. The pavilion creates a foggy ambience of its own inside using sound, smell and media projection to attract its users. Epiphyte’s water core becomes the fireplace of the 21st century, providing an interesting space, where people gather, meet and interact with each other [5].

Figure 2. Mario Caceres, Cristian Canonico, "Treepods" in Boston's urban space, 2010 [6]

Trees work as natural air filter of particulate matter and pollutants. Therefore, designers Mario Caceres and Cristian Canonico have designed a set of street-sculpture air-filtering trees for "the SHIFTboston urban intervention contest" held in October 2010. These designs, called Treepods, harness biomimicry to efficiently emulate the carbon filtration qualities of trees (Figure 2). Boston Treepods is an urban intervention which contains a system that is capable of removing carbon dioxide from the air and releasing oxygen using a carbon dioxide removal process called “humidity swing”. In addition to cleaning the air, the Treepods will also generate energy with solar energy panels while harvesting kinetic energy through an interactive seesaw that visitors can play with at the Treepod's base. When a person plays on the see saw, the power display explains the Treepod's de-carbonization process. The solar panels and the kinetic energy station are used to power the air filtration process, as well as interior lighting [6].

The examples presented above are only some of the latest results of the multi-disciplinary research on how to improve urban ecosystems. In addition, they show how man-made urban elements are affected by culture, personal behaviour, politics, economics and social organisation. Digital technology has opened up new opportunities in various fields. Designers and scientists around the world can learn from Nature to imitate not only the shape of various living forms, but to imitate similarly looking functions, processes and spatial systems. They also believe that art has a role to play in shifting people's ideas about how to improve the built environment. It can also be part of the solution in rebuilding ecosystems in the built environment.

3. Research and methods
When Janine Benyus published her book, “Biomimicry: Innovation Inspired by Nature” in 1997, she expected it to cause a stir in the academic world. She didn’t imagine it would help launch a movement that has reshaped the way many architects, designers and engineers approach their disciplines [7]. Over the past decade, biomimicry has burrowed small but persistent roots into the foundation of architecture.
3.1. Biomimicry and Biomimetics - design process and design strategies

At the end of the 20th century, a new concept imitation of Nature emerged. According to this idea, Nature's models and imitating natural designs have to solve human problems. Nature is treated as a "Model, Measure, and Mentor" on a path toward sustainability. This approach to design is called "Biomimicry". There is no real difference between the terms "Biomimicry" and "Biomimetics", however "Biomimicry" is used in developing sustainable design solutions and "Biomimetics" has been applied to technologies honed from bio-inspired engineering at the micro and macro scale levels [7]. In order to create designs as Nature does in its environment, it is important to understand what the emergence of natural form-shaping processes are and to gain knowledge how to apply mathematics to describe these processes in the ways which are useful to designers. A well-known researcher Michael Pawlyn, who is the pioneer of using the design strategy "learning from Nature", is supporting the idea that "the principle for architecture that emerges from observing is: less materials, more design" [1]. According to this point of view, it is necessary to have some design strategies to built biomimetic buildings in architecture.

Figure 3. Biomimetic design process and design strategies [8]

Figure 4. Biomimicry top-down and bottom-up approaches [14]

Biomimicry is used as a design strategy in the field of architecture. This design strategy has a potential to balance the relationship between nature and humankind. Frosch and Gallopouls recommend imitating ecosystems, as this strategy can lead to new relationships between the built environment and society [9]. After this suggestion, Benyus backed up this idea. She highlighted that science, biology, building technologies ought to collaborate to satisfy ecological aims. So, if the interaction between nature and designers went past the analogy concept and achieved a metaphoric level, a total learning procedure would be achievable [7].
Initiatives from both biomimetic and design communities have produced numerous manifestos describing key principles and methodologies deduced from existing practice, coupled with tools that offer guidance in biomimetic thinking, project management and design [10]. As it is shown in Figure 3, the main principles of biomimetic design include: evolving to survive, adapting to changing conditions, being active in terms of finding resources (material and energy), being locally sensitive, integrating growth with development, being responsible and using nature-friendly chemicals.

According to an examination conducted by Pedersen Zari at Victoria University in New Zealand in 2007, two distinct approaches to biomimicry as a design approach exist: Problem-Based Approach and Solution-Based Approach [11]. These approaches each have their own advantages, disadvantages and outcomes in terms of overall sustainability.

This Problem-Based Approach was found to have different naming in various literature items such as “Biologically Inspired Design”, “Problem Driven Biologically Inspired Design” [12], [13] and “Top-Down Approach” [14] (Figure 3), all having the same meaning. In this approach, designers look to nature for solutions, recognise their design problem and look at how organisms and systems in nature have solved similar problems. One possible drawback of this design approach is that the issue of how buildings correlate with each other and the ecosystem they are part of is not investigated. Therefore, the underlying causes of non-sustainable or even degenerative built environment are not necessarily addressed. Nevertheless, the Problem-Based Approach may be a good way to begin the transition of the built environment from inefficient to a more sustainable one.

The Solution-Based Approach is also referred to as “Biology Influencing Design”, “Bottom-Up Approach” or “Solution-Driven Biologically Inspired Design” (Figure 4). In this approach, biological knowledge influences human design. One of its advantages is that the knowledge of biology may influence the design in the ways other than the predetermined design problem. One disadvantage is that an in-depth biological research must be conducted, then the information gathered must be determined as relevant in a design context [11].

Over the years, the biomimetic approach to technology and innovation has increasingly received attention as an alternative for the ecosystem destroying technologies of the industrial age. Such thinking might lead some to reconsider the very nature of architecture itself. Neri Oxman has been vocal in promoting a new kind of architecture based on natural principles, such as growth over assembly, integration over segregation and difference over repetition, which are now made easier by digital fabrication technologies. Nowadays, the ecological and sustainable design focuses on the theory and practice of architectural and urban design that makes maximum use of the same renewable flows of energy and material cycling processes by which all other living systems on earth are sustained. As it is well known, there are three principles of sustainability in architecture which can provide a broad awareness of the environmental impact: Economy of resources is concerned with the reduction, reuse, and recycling of the natural resources that are input to a building, Life cycle design provides a methodology for analysing the building process and its impact on the environment, and Human design focuses on the interactions between a human and the natural world [15]. The capacity for building envelope to actively support building function is critical to the future of building design.

3.2. Research for an energy-efficient “eco-event”

Nature has been sustainable and energy efficient for billions of years. Natural organisms have evolved and developed strategies in order to be energy efficient. Through applying these characteristics into architecture, human problems can be solved. Mimicking nature has significant potential to achieve a new approach to designing an energy-efficient building. Through discovering and emulating nature’s strategies, the energy consumption level can be decreased by applying the biomimicry approach.

Last year, these issues were undertaken by Krystyna Januszkiewicz, the Leader of Digitally Designed Architecture Lab and the faculty member at WPUT (West Pomeranian University of Technology) in Szczecin. The programme combines techniques and strategies of digital parametric modelling with research concerning the behaviour of materials and structures. This research also constitutes a part of a broader area that determines how to draw inspirations from Nature and how to
apply visual and conceptual designs in architectural projects. There are studies that demonstrate that imitation plays an important role in establishing the relationship between the environment and society [8]. These research studies highlight that science, biology, construction technologies ought to collaborate to satisfy ecological aims.

The main aim of the research designing programme was to demonstrate the application possibilities of creating nature metaphors in designing an architectural object that could be defined as the “eco-event” in the built environment. In the first part of the research project, design strategies and design processes were defined. Different approaches to the topic were considered, with a focus on the biomimetic and biomimicry thinking of imitation in designing architecture with using advanced technology. Biomimetic design strategies were adopted such as: evolving to survive, adapting to changing conditions, being active in terms of finding resources (material and energy), being locally sensitive, integrating growth with development, being responsible and using nature-friendly chemicals. The second part of the research goes on to attempt to apply the biomimetic principles in architectural design with the use of digital parametric design tools.

3.2.1. Learning from the leaf

Each leaf is a multilayer structure (Figure 4). Leaf tissues are composed of layers of plant cell such as the epidermis and the mesophyll layer with different types of cells. The epidermis secretes a waxy coating called the cuticle that helps the plant retain water.

![Figure 5. Leaf pattern for design and anatomy diagram [16]](image)

The epidermis in plant leaves also contains special cells called guard cells that regulate gas exchange between the plant and the environment. Guard cells control the size of pores called stomata (singular stoma) in the epidermis. Opening and closing the stomata allows plants to release or retain gases including water vapour, oxygen, and carbon dioxide as needed. The middle mesophyll leaf layer is composed of a palisade mesophyll region and a spongy mesophyll region. Palisade mesophyll contains columnar cells with spaces between the cells. Most plant chloroplasts are found in palisade mesophyll. Chloroplasts are organelles that contain chlorophyll, a green pigment that absorbs energy from sunlight for photosynthesis. Spongy mesophyll is located below palisade mesophyll and is composed of irregularly shaped cells. Leaf vascular tissue is found in the spongy mesophyll. Leaf veins are composed of vascular tissue. Vascular tissue consists of tube-shaped structures called xylem and phloem that provide pathways for water and nutrients to flow throughout the leaves and plant. Plant leaves help to sustain life on Earth. Would they be able to do the same with buildings?

4. Results

Transforming today’s built environment into sustainable climate change-friendly cities is one of the main adaptations that will soon be a necessity. Ecological engineering and architectural design offer a
holistic approach, a wide spectrum of possible solutions such as an idea named "eco-event" in the built environment. In this concept, architecture has the ability to create active space and stimulate people to act and to implement urban ecology worldwide. The presented concept of the architectural object that was inspired by the tissue found in plant leaves has resulted from the previous studies and conducted research.

4.1. The Sun and Shadow Pavilion as an “eco-event”

The design named "Sun and Shadow Pavilion" mimicked a leaf, its structure, processes and shape. It allowed for the development of a protective multi-layer envelope for curvilinear buildings located in polluted cities and agricultural areas. The coating was designed so that it could perform tasks such as collecting solar energy and rainwater, as well as cleaning the air outside and inside the building, providing the right microclimate depending on the weather conditions and the level of air pollution.

Figure 6. The Sun and Shadow Pavilion – formation of initial concept (Meryem Alagoz)

The architectural design was based on the natural leaf anatomy and processes that occur in the leaf during photosynthesis and respiration. Photosynthesis is the combination of carbon dioxide and water with solar energy to create carbohydrates, giving off oxygen to the atmosphere as a by-product. The carbohydrates are used during respiration, which is the reverse chemical reaction, to produce energy that is necessary for a plant to grow. The project has begun with a detailed analysis of the project brief and the formation of an initial concept – a leaf motif with dew drops as a building envelope (Figure 6).

Form generation: Form generation does not necessarily need to be based on evolutionary software. The initial form generation of the The Sun and Shadow Pavilion commenced by employing a parametric technique that allowed free surface modelling based on NURBS, a mathematical model commonly used in computer graphics for generating and representing curves and surfaces. Non-uniform rational basis spline (NURBS) offers great flexibility and precision for handling both analytic (surfaces defined by mathematical formulae) and modelled shapes. Rhino 3-D-modelling software
packages offer a variety of tools for geometric surface analysis. The Zebra analysis in Rhino, for example, uses (NURBS) surface evaluation and rendering techniques to aid visual analysis of surface smoothness, curvature, continuity between surfaces, and so on. Today, NURBS are commonly used in computer-aided design (CAD), manufacturing (CAM), and engineering (CAE), and are part of numerous industry wide standards.

When the geometry of the architectural form is the result of performative analyses, it ceases to be a form as such, and is considered as a material formation. Therefore, the essence of such design lies in the rules governing relationships and the model illustrating structural and material relations. Digital models obtained by this way are structural models, in which the relationship between material parts and the whole form can be modulated parametrically, numerous industry wide standards.

Performative abilities: the pre-fabricated plant leaf is designed to have zero carbon emissions, collecting energy at daytime and using it for media projection at night. It is a multi-layered envelope (Figure 6a) which performs the following environmental tasks: energy storage (thin film solar cells); air purification (nano coating); natural ventilation (aerodynamics and holes); rain water collection and filtration; art projection (media internal facade and floor) (Figure 7a-b).

Figure 7a-b. The Sun and Shadow Pavilion a) performative layers’ diagram, b) PV envelope visualisation (Meryem Alagoz)
The PV envelope is adapted to collect and store rainwater for on-site reuse. The pavilion collects rainwater storing the grey water in a central core (under the floor), where it is filtrated, cleaned, vapourised and used by the mist system to cool down the surroundings and the thin film photovoltaic cells on the roof in the summer time. This water is also used for cooling the air inside the object through the process of evaporation. The shape of the PV panels is also a pattern on the interactive floor of the pavilion (Figure 7b). This is an important element of the inner space that has the ability to reconfigure itself and automate physical change to respond and react to user movement.

The next layer of the envelope has a lot of ventilation holes that look like leaf’s stomata. The cladding of this layer is covered by a TiO\textsubscript{2} nano layer of the shaped leaf that reacts to ultraviolet rays enabling the reduction of air pollution, cleaning the atmosphere around the pavilion, the pavilion creates a foggy ambience of its own inside using sound, smell and media projection to attract. It benefits from its green or urban surrounding, while providing a new and interesting space for exhibitions and art installations. The Sun and Shadow Pavilion manifests the possibilities offered by latest technologies that can be addressed to improve the quality of the built environment. The “eco-event” object can be adaptable for city squares as well as agricultural areas, to create a meeting point for people. It promotes the eco-philosophy and values.

5. Conclusions
Biomimicry, as a new way of viewing and valuing nature, introduces an era based not on what we can extract from the natural world, but what we can learn from it. It is one of the fields where architects, biologists, environmentalists, to name but a few, can all work together for a better sustainable living.

Creating a sustainable built environment is not done just by integrating solar panels on a building, but humans need to be more in tune with Nature and look to Nature for inspiration. The use of biomimicry has generally been considered a new discipline to solve human problems, so it can be used as an integrative architectural design component to achieve sustainable ecological design and create complete unity between the building, the users, and the environment. The leaf surface having several cellular openings involved in gaseous exchange and transpiration in plants may be considered the building envelope. The Sun and Shadow Pavilion designed according to the biomimetic principles goes on to attempt to solve the problem for today and tomorrow. The design highlights that it is possible to make new designs based on nature’s principles and also be eco-friendly, self-sufficient, energy efficient. For these reasons, it can be treated as an eco-event that integrates people and encourages social debate - as a place to develop and explore novel theories, methods, research, and policies that are needed to underpin the conservation, restoration, and maintenance of the natural heritage that sustains life and human opportunity.

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