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# Bionic aspects in the search of functional systems of structural surfaces

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## ABSTRACT

The search of experimental architecture is followed by an increasingly more visible manifestation of the transition from shaping the biomimetic design to the biomorphic. The forms which architectural objects take, cease to be inspired by the aesthetics and the shapes found in nature. The shaping of new and unprecedented forms is the result of natural forming processes. Such a design often allows for the creation of complex spatial structures, optimized in various respects. "Applying" the biological models to architecture also includes processes and designs found in Nature to shape the facade systems and their material technology. As a result, the architectural "skin" becomes multifunctional and ceases to serve only as a masking and isolating function between the exterior and the interior. The bionic elevations inherently focus on transformation and circulation of matter, and their flow of information and energy. The use of digital tools to make complicated numerical analyses significantly affect the acceleration and facilitation of proper simulation of the environmental conditions and the impact on the environment of the designed building. As a result, the bionic design allows for the mapping of ecosystems, processes, functions and materials found in the natural world and for the design of sustainable, efficient and innovative architecture with specific aesthetics. The innovative facades have become an essential part of the integration of intelligent buildings into the environment, at the same time becoming one of the architectural trends. Consequently, the search for contemporary experimental designs based on bionic patterns leads to the development of new solutions for structural surfaces.

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## Introduction

It is becoming more and more evident that modern technology is focusing on nature. Scientists increasingly search for processes and functions which can be observed in living organisms. Thus, bionics, as an interdisciplinary field of science that studies the functioning of living organisms is beginning to play an important role in the search for new technologies, also in construction. Consequently, we can distinguish façade systems performing functions modelled on nature, or determining the basis of the processes, i.e. rules of operation. By combining each setup, it is possible to obtain a multi-system, which will allow for the adjustment of the object to changing environmental conditions. Shaping structural surfaces may include the use of systems and technologies, constituting an important aspect of the bionic design in search of functional references. We can distinguish bionic systems used in modern structural surfaces, the main objective of which is to influence the internal environment affecting the reception of the building, or its relationship with the external environment as well as contributing to the efficient building functionality as an independent entity.

## Bionic systems affecting the internal environment of the building

Functional systems transposed into architecture, inspired by phenomena observed in the natural world, can be transferred to architecture in the form of a system, the main purpose of

which is to control the climate inside the building. This aspect of modern solutions consists of passive and active temperature control, the flow of natural ventilation and flexible and dynamic elevation solutions to freely determine both the interior and the outer surface of the building. The most popular elements allowing for this control include shading systems. Research in the field of bionic solar shading systems is aimed at seeking systems that will react spontaneously to the changing weather conditions without the use of additional electronic systems, similarly to the skin of living organisms or stomata in plants. The HygroSkin project is an example of such an idea in use. The dimensional instability of wood in relation to the humidity level was used in the “architectural skin”, which reacts to the fluctuation in external conditions. The housing elements open and close independently in response to the changes in weather solely by means of its material properties. Another example is homeostatic elevations, which operate based on physical phenomena, eliminating the need for additional power supply. The system inspired by the functionality of muscles and tendons performs a similar function to the stomata in the leaves of plants which prevents the loss of humidity upon closing. The system’s method of operation is based on the use of flexible polymer combined with silver-coated elastomer. The components of the “Venetian Blinds” deform because of the heat, thereby preventing further heating of the interior of the building, and in turn, eliminating the effect of overheating of the room. A very similar system was used in the Smart Skin shading elements.

The modern methods used in dynamic systems include remote motion control and the original method of shaping. An example of the mobile system elements used in the designed façade is the elevation of the Arab World Institute in Paris, a project by Jean Nouvel. The southern facade of the building was composed of square modules, similar to the Arabian mashrabiya (openwork windows), forming a grid of aluminum profiles with glass and aluminum panels. The panels have a built-in mechanism which controls them using a computer adjusting the incoming light. The elevation of the Al Bahar Towers skyscraper in Abu Dhabi is another example of the use of mashrabiya-inspired dynamic panels. A study of the behavior of local species of plants enabled the façade shading modules to be shaped, which can be set in three positions (open, half-closed and closed). A single module is made up of 15 triangular PTFE elements placed within the aluminum and stainless steel frames.

The search for a way to introduce “movement” for the needs of flexible architecture in shaping the inside of an object is noticeable also in the creation of dynamic façade elements. The shading facade panels are usually movable elements as in the case of the Kiefer Technic Showroom building. The dynamic facade from the Giselbrecht + Partners design office can adapt to changing conditions and requirements of the tenants, creating a long-term variable surface. The result is a flexible elevation adapting to the requirements both in terms of comfort and functionality of the object. Similar effects can be achieved using the Flare Facade System, facade components of which are computer controlled and can react to changes in the environment.

The inspiration for the design of bionic architecture elements also includes structures created by living organisms such as termite mounds or anthills. These studies are an

inspiration in the search for systems allowing for natural ventilation that can be observed, inter alia, in the way termite mounds are formed. The mounds are built to allow for the flow of air through small holes located in the lower parts. The air flows through the corridors to the top of the mound, where it is then blown away. The air flow regulates the closing of the holes and the creation of new openings by insects. Consequently, despite the large variations in temperature prevailing outside, a constant temperature is maintained on the inside. The corridor system provides ventilation; it also cools the air in summer and heats it in winter by conducting the air underground.

A similar solution inspired by the termite mound structure was used in the Eastgate Centre building designed by the architect Mick Pearce and Arup studio engineers. The facility installed a fan system and ventilation ducts, which maintain a constant temperature inside the building. As a result, the energy consumption for air conditioning was minimized. Natural ventilation concepts are being transferred to form the ventilation in the interlayer of the double wall facades. The rotatable wall of Walter Kroner's project is one of the first ventilated facade concepts. The facade consists of rotating prisms with a triangular cross section, the sides of which have different properties – allowing for natural ventilation, energy generation from solar radiation and provision of the energy accumulated during the day into the inside of the building. The development using the double facade technology has led to many solutions for shaping the facades using natural ventilation. Twin glass curtain walls with an outer layer equipped with natural ventilation valves have been incorporated in the design of the Grattacielo Intesa Sanpaolo skyscraper. The natural air circulation is achieved by opening an inlet channel, enabling further cooling of the structure.

Another type of technical solution that allows for natural ventilation of the building is the use of a natural phenomenon which is the result of the solar chimney air suction used in the Hydroplace Mantiba high-rise building. By means of an appropriate double glass facade configuration it was possible to achieve a natural draught, which was humidified by the water curtain, causing the cold air to heat in the winter and cool in summer.

### **The bionic systems affecting the functionality of the building as a unit**

Inspirations from the functioning of the natural world are also an important aspect in the development of sustainable architecture. Adaptation to the environmental conditions played a major role in shaping the architecture, the aim of which is to constantly reduce the negative impact on the natural environment. The need to obtain energy from unconventional sources, as in the case of plants and animals, is significant. Each building needs energy in order to function properly, just as living organisms need nutrients. Chemical reactions and metabolism are important to enable the cells to grow, to manage their structure, or respond to external stimuli. Modern technology allows for energy extraction from solar radiation using solar panels or photovoltaic modules as in the case of the Solar-Fabrik office building in Freiburg. The elements of PV cells imprinted on glazing and integrated in the design of facades are becoming increasingly popular, both in solar and photovoltaic modules.

Elements harnessing energy from the movement of air masses are used on the facades. Renewable energy is produced by wind turbines, which are situated in areas of increased movement of air masses within the location of the object, as seen on the Bahrain World Trade Center building in Manama, Bahrain – an Atkins studio design, where windmills are located between two bodies of the building. It is also possible to harness energy by shaping the object correctly, as in the case of the Perl River Tower skyscraper in Guangzhou, China. Wind turbines have been placed between floors, while at the same time the building was positioned to face the prevailing winds in order to achieve an effect similar to that of a sail. As a result, the designers of the Skidmore, Owings and Merrill studio optimized the form of the object due to the efficient energy generation. The wind turbines in the Bahrain World Trade Center building in Manama, Bahrain (Atkins design studio) have been used in a similar way, being placed between the two building structures. Among the contemporary design trends one can observe prototype solutions using biochemical reactions occurring in plants in the so-called bioactive facades. The solutions use biophotonic devices that enable the cultivation of plankton algae, so-called bioreactors. A very interesting example of this is the BIQ House building presented at the International Building Exhibition (IBA) in Hamburg in 2013. The microalgae implemented on the facade not only harnessed energy, but also acted as a sun visor. The clusters of algae forming bioreactors were placed in glass panels of external blinds fixed to the ceiling structure. A similar example where biophotonic elements are to be applied is the conceptual design for the BIO2 skyscraper in Nanterre, a suburb of Paris. The German Strategic Science Consult in cooperation with Colt International and Arup are conducting interesting research on the effectiveness of a bioactive façade. [Gugu 2012] For example, the apartment created by the Austrian Splitterwerk Architects has become a recognizable icon of Hamburg, among others, thanks to its biofaçade. The search for the use of naturally occurring processes harnessing energy is entering the next phase of research. The prototype biological photovoltaic panel solutions designed at the Institute for Advanced Architecture of Catalonia is, in this context, important evidence in the debate on the scope of the possibilities of using natural processes. In the research project the biological photovoltaic panels are a breeding ground for bacteria and plants, the geometry of which has been formed on the basis of Voronoi diagrams. Upon entering the anode and cathode, the bacteria “obtaining” by-products from plant photosynthesis, release free electrons that can be extracted and put into circulation. The functioning of complex organisms is an inspiration in the search of intelligent management systems. Basic subconscious life functions such as breathing or heartbeat and automatic control of these processes under the influence of changes in various factors can provide an important impetus to simulate similar processes in architecture. As a result, modern architecture can increasingly become an organism in which the respective management systems ensure its efficient functioning. With the right management systems, the building is able to “react” to any changes in the environment responding to the needs of users, control the flow of energy in relation to the number of people staying in different sectors, and even allow for proper management of the rented building. The so-called “smart” buildings are being

increasingly equipped with a BMS (Building Management System) to help manage the facility during its operation. As a result, it is possible to obtain factor information affecting the comfort, safety and the impact of the building on the environment, as well as analyzing, among others, power consumption. Automatically controlled devices make it possible to achieve a suitable indoor climate. The BMS control systems have been primarily used in façades, among others, in the Al Bahar towers in Abu Dhabi. By opening and closing the management modules, we can prevent excessive, direct sunlight from reaching the interior. The units are controlled by a linear servomechanism that adjusts the opening of the covers according to a predetermined sequence. In addition, the system is equipped with sensors automatically opening and closing shutters during wind or rainfall. The modern management systems have also been used in the Media-TIC office building in Barcelona. There are triangular elements on the facade of the building, each of which is equipped with its own microprocessor that adjusts the temperature conditions and regulates the amount of sunlight reaching the building. The steel construction of the facade was finished-off with ETFE foil cushions and photovoltaic modules. In addition, the southern façade is made of pillows filled with steam, protecting the room from overheating.

### **The bionic systems affecting the perception of the building and the external environment**

Modern facades are multifunctional surfaces, which can also affect the external environment. The ongoing urbanization and the development of our civilization have an adverse effect on the living conditions in urban areas. High levels of pollution and a limited number of green areas are often one of the most important elements affecting the urban environment. Active facade surfaces can possibly improve these parameters.

As a result, the application of a titanium dioxide coating in architecture reduces air pollution on a constant basis. Such a coating was applied on the facade of the Manuel Gea Gonzalez hospital in Mexico City. The elevation of the facility consists of prosolve370e modules designed by Elegant Embellishments (Allison Dring, Daniel Schwaag). Prosolve370e modules are three-dimensional, decorative architectural elements that use photocatalysis technology in order to reduce the amount of pollution in the air (photocatalytic pollution-countering technology). As a result, the modules are coated with titanium dioxide and are activated by light.

Yet another solution to minimize contamination is the design of green walls that additionally assist in protecting the building from weather conditions, which in turn leads to a reduction of energy loss used for heating and cooling buildings. By producing oxygen and absorbing carbon dioxide, the use of plants is particularly important in improving air quality. By using linear elements and grates under the vines, the green facades can be freely shaped. An example of such a system is the Cristal Park office building in Warsaw, a JEMS Architects project. In the art of designing green façades, architects increasingly turn to technology and material solutions enabling the formation of greenery surface systems. The technology for creating vertical hydroponic gardens was used, among others, in the Quai Branly Museum in Paris, a Jean Nouvel project in collaboration with the botanist, Patrick Blanc.

The technical solutions used for air purification and adequate air preparation have been used in the Hydroplace Mantiba building, which purify and control the humidity level of the air that enters the building. The facades of architectural objects increasingly provide us with informative functions similar to the colors of plants and animals. Media facades constitute a particular form of expression. The entertainment center elevation of the Xicui building in Beijing is an example of such a facade, which uses multimedia elevation combined with PV cells. The LED technology was used in the double façade media elevation of the Center City shopping mall in Cheonan, a project from the UNStudio design studio architects. An example of such media facade architecture was used in the “blob” Art Museum in Graz. The front facade was equipped with 40 cm diameter fluorescent tubes forming a BIX installation allowing for the projection of images composed of “pixels”. Today, in addition to the modules forming the opaque media surfaces, a type of grid-mesh media is used that provides both the projection for the images and information, as well as the translucency of the facade.

The camouflage present in the natural world also fascinates architects. This effect is used in architecture as part of the illusion that “plays a trick” on the human eye. Using the right methods, it is possible to achieve the perfect geometry of an object (ancient) or the illusion of movement. This illusion is visible in The Aqua Tower high-rise building in Chicago, which was successful in imitating a rippling facade. By adding a cuboidal high-rise system of organic-shaped terraces to the classic form of the building, a form of calcareous sedimentary rocks has been achieved.

The dynamism, which is also characteristic of living organisms, fascinates architects seeking variables and external stimuli able to respond to architectural elements. An interesting example of bionic design in this context is the “transfer” of traffic to the architecture resulting in the dynamic HypoSurface façade. The wall of the building designed by the deCOi group was a kinetic façade, responsive to repositioning elements in its environment. The interactive plane was designed parametrically and is converted by means of pneumatic elements connected to the control system. The newly created installation is a very good example of an interdisciplinary design by incorporating moving parts to the static architecture.

## Summary

The modern image of forming structural surfaces while respecting bionic facade systems creates a new way of qualitative architectural façades. The mapping of processes occurring in nature allows for the initiation of new technical and operational functions of structural surfaces. The functional bionic systems form integrated systems allowing for the operation, both at micro and macro level, of the building in the surrounding environment. The search for models and building control systems opens up the opportunity to obtain energy from unconventional sources and the ability to shape the buildings modelled on living organisms. Pioneering trials and experiments lead to the integration of these two elements obliterating the boundary between technology and biology. The search in the design of biomimetic architecture is conducted both in terms of facade systems and new material technologies, enabling the development of dynamic, active and modern solutions responsive to the challenges.

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**Aspekty bioniczne w poszukiwaniu systemów funkcjonalnych powierzchni strukturalnych****STRESZCZENIE**

W poszukiwaniach eksperymentującej architektury następuje coraz bardziej widoczny zwrot, objawiający się przechodzeniem z kształtowania biomorficznego na projektowanie biomimetyczne. Forma obiektów architektonicznych przestaje być inspirowana estetyką i kształtami spotykanymi w naturze. Kształtowanie nowych, niespotykanych dotychczas form jest wynikiem naturalnych procesów formotwórczych. Takie projektowanie umożliwia często tworzenie skomplikowanych, optymalizowanych pod różnymi względami, struktur przestrzennych. „Przenoszenie” modeli biologicznych do architektury dotyczy również procesów i wzorców spotykanych w naturze w zakresie kształtowania systemów elewacyjnych i ich technologii materiałowych. W efekcie „skóra” architektoniczna staje się multifunkcyjna i przestaje pełnić jedynie funkcję maski i izolacji między zewnątrz a wewnątrz. Bioniczne elewacje z natury rzeczy nastawione są na przemianę i obieg materii oraz przepływ informacji i energii. Wykorzystywanie narzędzi cyfrowych, umożliwiających dokonywanie skomplikowanych analiz numerycznych, w znaczącym stopniu wpływa na przyśpieszenie i ułatwienie właściwej symulacji warunków środowiskowych i wpływu projektowanego budynku na otoczenie. W efekcie projektowanie bioniczne, umożliwiające odwzorowanie ekosystemów, procesów, funkcji i materiałów spotykanych w świecie przyrody – to projektowanie architektury zrównoważonej, efektywnej i innowacyjnej, o specyficznej estetyce. Nowatorskie fasady stają się istotnym elementem integrowania ze środowiskiem inteligentnego budynku, wpisującego się w trendy architektoniczne. W efekcie – współczesne eksperymentalne poszukiwania projektowe, bazujące na wzorach bionicznych, prowadzą do kształtowania nowych rozwiązań powierzchni strukturalnych.

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