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Climate Change Oriented Design – Learning from Nature – Nature and Advanced Technology

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Abstract – This paper explores the possibilities of architectural design to benefit human condition, which encompasses physical environment of a safe life during the climate change era and predicted disasters. The first part deals with the problem of natural hazards and disasters during the climate change era and as a results human beings reacting to them. The second part presents, among others, results of the research program undertaken at West Pomeranian University of Technology in Szczecin by the author. The program is focused on the adaptive built environments and envisioning new solutions based on advanced digital technology. The research is going to find out ways to create the design of Nature inspiration architectural forms. Biomimicry approach is used as a design strategy in architectural design. Presented designs contain a systemic solution to the problems of health and security in high-urbanized areas during the climate change era. In conclusion it is emphasized that living organisms have evolved well-adapted structures and materials over geological time through natural. For this reason, "Learning from Nature" is one of the design methods that can provide new solutions to help mitigate the effects of climate change in a built environment and adapt to them.

Keywords – *Climate change, architectural design, nature, biomimicry, technology*

I. Introduction

"Does humanity have the chance to endure successfully on planet Earth, and if so, how?"[1]. This is the question framed by Buckminster Fuller (1895-1983), 20th century influential environmentalist, inventor and visionary. In the 21st century, this question makes a new sense refered to the global climate change impacts. The UN Climate Panel estimates that the global average temperature at the end of this century will be 2-4°C higher than today, if we continue our way of living [2]. Recently, architects and structural engineers, urban planners, health and physical scientists have started to work on specific solutions how urban environment should interact in the face of global climate change, natural disasters and other hazardous events [3].

II. Materials and Method

The idea of sustainable development was the first step to integrate various scientific fields and the integrity of people interested in the future of our planet. It was a shift towards interdisciplinarity in science and revision of the relationship between man, Nature and Technology. In the second half of the twentieth century, scientists reported that the planet is in bad condition and the energy sources are ending and in the atmosphere there are ozone holes. For this reasons, the development of carbon and oil-based technology must also go to the end and people must look for new energy sources and new technologies. In the 1970's Sim van der Ryn knew that building industry will soon require environmentally-friendly and energy saving solutions. Specialists from various disciplines gathered around van der Ryn interested in searching for innovations and new technologies. Not only was the research institute opened which worked on these solutions to architecture, but also implemented them. The idea of sustainable development has quickly spread throughout the world, becoming the guiding principle for both science and technology. However, politicians and big business were stubborn and did not want to change anything. Linking this idea with the pro-ecological approach to the built environment was to lead to changes in social activity and behavior. At the end of the 20th century, it became clear that increasing levels of greenhouse gases would lead to global climate change on Earth. Then a new concept of energy-saving buildings emerges. According to this idea Nature imitating built environment is the intended to solve human problems, in order to successfully survive on Earth. Nature is treated as a "Model, Measure and Mentor" on the road to a sustainable development.

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 that 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 human and the natural world. The capacity for building envelope to actively support building

function is critical to the future of building design during the climate change era.

Humans have made an indelible mark on the planet. There is now "overwhelming global evidence that atmospheric, geologic, hydrologic, biospheric and other earth system processes" have been transformed by human actions. Humans found guilty in the global climate change. The planet's average surface temperature has risen about 0.9 degrees Celsius since the late 19th century, a change driven largely by increased carbon dioxide and other human-made emissions into the atmosphere [4].

According to world researchers, we should introduce measures to ensure that the temperature would not exceed more than min. 2°C compared to the level before industrialisation. With a temperature higher than 2°C, there is a risk that we will develop climatic challenges we cannot slowdown, which can lead to consequences for both the way we live today and for all life on earth. The Special Report on Global Warming of 1.5° C was approved by IPCC on October 8, 2018 in Incheon Republic of Korea. It was a key scientific input into Katowice Climate Change Conference in Poland in December, governments review the Paris Agreement to tackle climate change [5]. The report find that limiting global warming to 1.5ºC would require "rapid and far-reaching" transition in land, energy, industry, buildings, transport and cities. Global net human-caused emissions of carbon (CO_2) would need to fall by about 45 percent from 2010 levels by 2030, reaching 'net zero' around 2050. This means) that any remaining emissions would need to be balanced by removing CO_2 from air [5]. Today a hot question is how should humanity adapt to such difficult living conditions?

A. Climate change oriented design as a new approach to architectural design

Climate change refers to a large-scale, long-term shift in the planet's weather patterns and average temperatures. The climate has always naturally changed, but when we talk about 'climate change', it means that the climate is changing in a more rapid pace than what it used to through the history of Earth.

Contemporary understanding of ecology should be changed the way in which architects approach to the built environment. Complex climate change-friendly architectural forms demand new tools and a new approach to design. Architects gain this through a design strategy that combines digital and material processes. The structures contain a multiplicity of stable states that link changing spatial requirements to a corresponding formal and structural articulation. With the use of parametric and multi-criteria optimization tools, buildings can be designed to respond to the various requirements. Architects or designers attempt to safeguard air, water, and earth by choosing eco-friendly building materials and construction practices. There is an increasing number of research, which concerns ways of providing crucial design parameters for creating performance structures, which allow buildings to react to changes in environmental conditions and minimizes harmful effects on human health and the environment[3]. The new approach has shifted questions of environmental-friendly away from the traditional formal and physical properties of building to reposition the discourse within a more expansive definition of how they behave. A new kind of design approach called the climate change oriented design is emerging.

Climate change oriented design can be defined as an adjustment of conditions compatible with changeable climate characteristics and ecology. In architecture the term redefines an architectural design process not as the shape of material object alone, but as the multitude of effects, the milieu of conditions, modulation and microclimates that emanate from the exchange of object with its specific environment - as a dynamic relationship that is both perceived and interacted with by a subject. An intention of this kind of design is to eliminate negative environmental impact through skillful, sensitive design. This requires a view broader than ever, with a heavy emphasis on various interdisciplinary aspects. The main mission of climate change oriented design is to build the designers own interpretation and implementation of environmental systems thinking. Therefore involving climate oriented design principles into architectural and construction phase of design contributes to reach more sustainable and climate-friendly built environment[6].

III. RESEARCH AND RESULTS

Climate change is impacting human lives and health in a variety of ways. It threatens the essential ingredients of good health – clean air, safe drinking water, nutritious food supply, and safe shelter – and has the potential to undermine decades of progress in global health. A few years ago these issues were undertaken by author (Leader of Digitally Designed Architecture Lab) and faculty member at the WPUT (West Pomeranian University of Technology) in Szczecin. The research program (Climate Change Adapted Architecture and Structure) is focused on design the adaptive built environment for modern societies and envisioning new solutions based on advanced digital technology. There are developed new strategies to anticipate exterior environmental variations as well as interior interaction with inhabitants to response to all the weather phenomena during the global climate change era. With the use of parametric design tools, and multidisciplinary knowledge design ideas are programed and represented visually in the form of diagrams, drawings, digital abstract or physical models and computer-generated images. This type of concept representation can not be appropriate for a precise, and unique material reality and further states that even the most convincing techniques of representation do not correspond fully to the experience of the built reality. Therefore, a representation is usually treated as a description of away of thinking and material systems.

A. Learning from nature with using advanced technology

During history, designers have looked to Nature as an inspiration source for different kinds of forms, techniques and function. Design methods were based on direct perception, observation and study of Nature. Architects have looked the nature for inspiration for building structures and their methodologies [7]. They have been searching for answers to their complex questions about different kinds of shapes, structures or processes, and they have mimicked a lot of forms from nature to create better and more efficient structures for different architectural purposes. Currently, living organismus have given rise to new technologies inspired by biological solutions at macro- and nano-scales.

Nature has solved engineering problems such as self-healing abilities, environmental exposure tolerance and resistance, hydrophobicity, self-assembly, and harnessing solar energy. Transforming today's cities into sustainable climate change-friendly cities is one of the main adaptations that will be necessary. Ecological engineering and architecture 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 create an activate space and stimulating people to act and implementation of urban ecology worldwide. The concepts of two architectural objects that were inspired by tissue found in plant leaves and the work of a natural network of neurons are presented.

Learning from the leaf

In nature, every creatures can produce their own energy, from this point of view, a leaf can also produce its own energy and due to its stomas can breathe and make photosynthesis for being alive (fig. 1). As mentioned the biomimetic design should be active in terms of finding sources (material and energy), be locally sensitive integrating growth with development, and responsible, and using nature-friendly chemicals. According to these principles the designed object looks like a leaf but not only a mimicry level but also having similar principle for This approach to of design can be named as design-looking to nature which is a category of biomimetic design approach.

The design named "Sun and Shadow Pavilion" mimicked the leaf, its structure, processes and shape, allowed for development a protective multi-layer envelope for curvilinear buildings located in polluted cities and agricultural areas. The coating has been designed so that it can 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.

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: surviving to improve, adapting to the changing conditions, being active in terms of finding sources (material and energy), being locally sensitive integrating growth with development, and responsible, and using nature-friendly chemicals.

The second part of the research goes on to attempt to apply in architectural design derivatives of 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 the plant needs to grow. According to this principle, firstly the design of architetcural object is based on leaf anatomy similarly.

The leaf anatomy: Each leaf is a multilayer structure. Leaf tissues are composed of layers of plant cell such as epidermis layers and a mesophyll layer with different tytpes of cell. The epidermis secretes a waxy coating called the cuticle that helps the plant retain water. 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 vapor, oxygen, and carbon dioxide as needed. The middle mesophyll leaf layer is composed of a palisade mesophyll region and a spongy

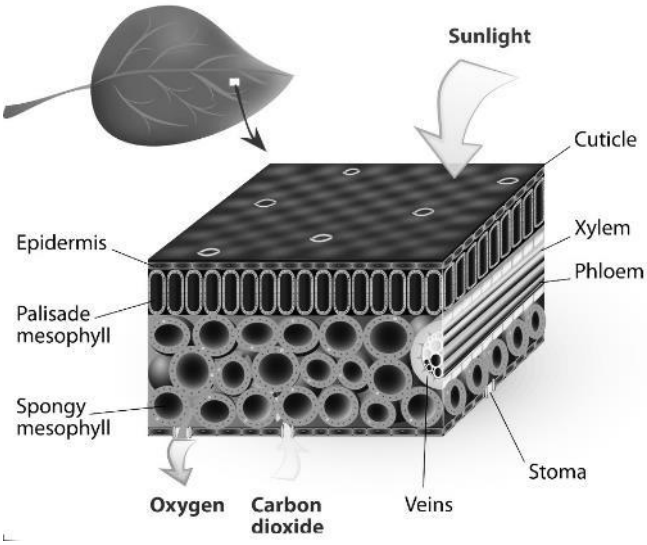

Fig. 1. The leaf anatomy diagram [16]

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 buildings?

Designing the Sun and Shadow Pavilion: Work on the project has begun with a detailed analysis of the project brief and formation of initial concept – a leaf motif with dew drops as a building envelope (fig. 2).

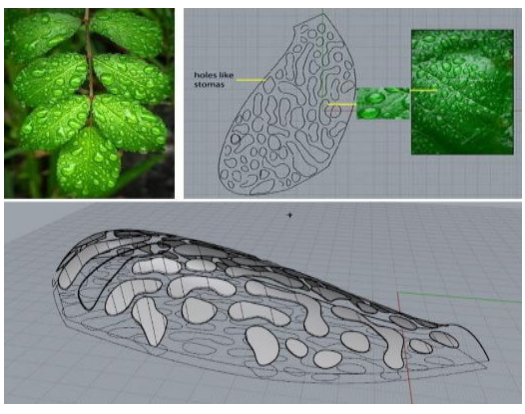

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Fig. 2. Meryem Alagoz, Sun and Shadow Pavilion – formation of initial concept

The pre-fabricated plant leaf is designed to have carbon-zero emissions, collecting energy at daytime using it for media projection at night. It is a multi-layered envelope (fig. 3) which performs the following environmental tasks such as:
- 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).

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 possibilities latest technologies that can be addressed to improve the quality of the built environment.

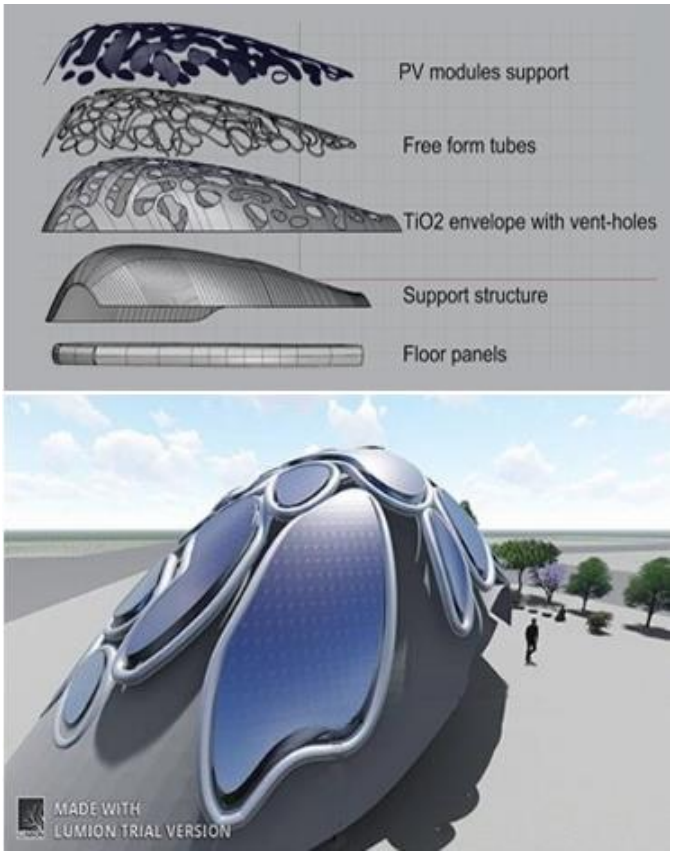

Fig. 3. Meryem Alagoz, Sun and Shadow Pavilion – multilayer sensitive building envelope

The first layer of the pavilion enwelope is a solar envelope adapted to collect and storage rainwater for reuse on-site. The pavilion collects rainwater 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 in the summer tiine. This water is used for cooling 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 (fig. 2). 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. Second layer of the envelope has a lot of ventylationm holes look like leaf's stomas. The cladding of this layer is covered by a TiO_2 nano layer of shaped anatase 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 its users. The Pavilion provids an interesting space, where people gather, meet and interact with each other. The portable pavilion can be adaptable for cities squares as well as agricultural areas to create a meeting point for people and promotes the eco-philosophy and values.

Learning from natural neuron network

The design is focused on protective envelopes designed for modern buildings in cities experiencing recent rapid development. The envelopes designed to have adaptation and protection strategies to anticipate exterior environmental variations as well as interior interaction with inhabitants[8]. With the use of parametric and multi-censor optimization tools, envelopes are programmed to respond to the certain criteria. Cities produce lot of energy e.g. sound, smell, friction, that is not used again, so it is worth widening the range of storage inputs.

In the first part of the research project, the main negative and positive factors affecting mental health in large metropolises are defined. The impact negative effects of climate change along with their correlation with depression are discussed (fig. 4).

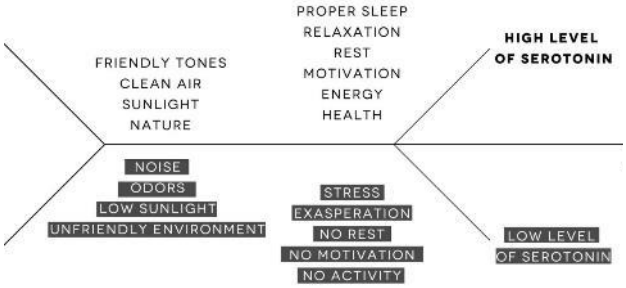

Fig.4. Environmental factors influencing depression and antidepressant factors diagram

The second part of the research program goes on to attempt to solve this problem through architectural design, using the latest technology and methods. The intention of this design was to not only to minimise but to eliminate any negative environmental impact completely. This was possible by using intelligent and sensitive design conceptualization. range of storage inputs.

The working principle was inspired through the basic principle of how biological neuron works (fig.5).

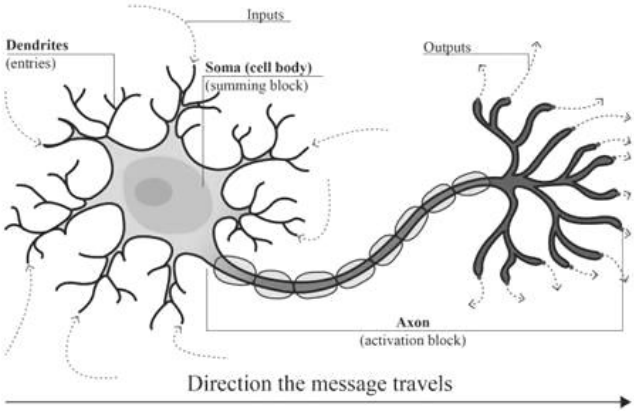

Fig.5. Basic principle of biological neuron working diagram

The neurons contain three important parts: the cell body that directs all activities of the neuron; dendrites which are short fibers that receive the message from other neurons and relay those messages to the cell body; and the axon, a long single fiber that transmits the message from the cell body to dendrites of other neurons. Every moment, messages are moving with amazing speed back and forth from neuron to neuron.

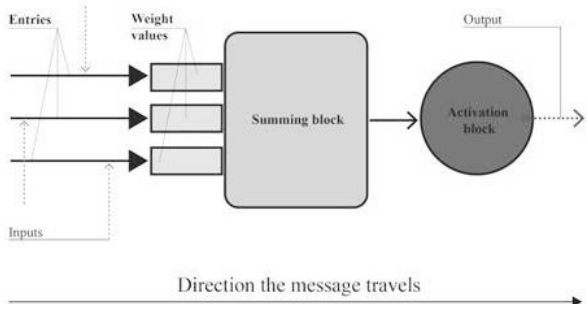

Fig.6. Basic principle of artificial neuron working diagram

The artificial neuron network receives one or more inputs (representing dendrites) and sums them to produce an output (representing a neuron's axon). The entry gets input signals. This is information that describes a task that the neuron has to solve (fig. 6). Each of the instruments has a certain value. The signals are multiplied by the weight values, the results of this multiplication are added together in a summing block. In this way, a specific number is defined as membrane potential. It is sent to the activation block where it can be processed in the future. The activation blocks receive an answer with a new value of the input signal [9].

Similarly, the stages of information processing through the building can take place by using three elements: the external envelope, which wraps the building and spreads to the streets of the city, collecting inputs from the environment. Gathering of the information – mostly negatives are processed in summing blocks located at the building base and released as positives into the interior by outer envelope (fig.7).

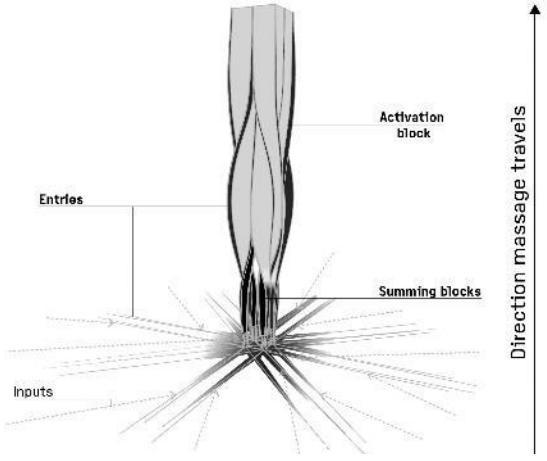

Fig. 7. Basic principle of building working diagram

Each of the environmental factors could be collected or processed by a personalized system. Inputs gathered from surroundings would be processed and released to the building interior with a new value. The intensity of released outputs could be controlled or manipulated by internal needs. It also could be combined in various ways to create the best expected microclimate (fig. 2). The following basic principles of building working have been considered:

- *Smell*: dirty air would be collected by the pores in facade. Odor from the surroundings is cleaned in a summing block using an air ionizer. Plasma discharge generates and emits the same positive and negative ions that occur in released into the air simultaneously would be used. These positive and negative ions instantly recombine on nature. Ion air purification technology in which positive ions [H+(H2O) n] and negative ions [O_2-(H2O) m] are the surface of bacteria, mold fungus, viruses and allergens floating in the air to form hydroxyl (OH) radicals, which have extremely high oxidation ability, and this chemical reaction decomposes proteins on the surface of bacteria and other pathogens, thereby inhibiting their activity [10]. This combination creates water which returns to the air. Cleaned air is transformed back to the interior of the building . Some of the pores in the facade contain selected natural, essential oils that are sprayed in the air in selected parts of the buildings in order to create a particular mood. For example: graveolens – a strong antidepressant, helps with emotional problems; grapefruit - improves mood and relieves nervous tension; peppermint – inhibits hyperactivity and lessens fatigue.
- *Sound:* A system of microphones could be mounted to the façade. Microphones are divided into 3 groups. Each group has a special membrane catching specific tones: low, medium and high. Particular vibrations go to the synthesizer that works like the sampler, recording sounds (the noise of the city) and then manipulating them in various ways by changing the sound settings into more friendly tones. Processed vibrations are released into the building through the different speakers as harmonic sounds of specific frequencies, which are friendly for the organism. For example, sounds with level of 136,6 Hz are relaxing for body, frequencies of 400 - 480 Hz decrease stress and are free from physical pain and raising vitality.
- *Natural environment:* rainwater could collect on the facade by a system of gutters with bowl-shaped heads. Single gutters would be connected to a main one hidden in facade that would direct water to the summing block for future cleaning and recycling processes. Recycled water is pumped back to the interior of the building and used for hydrating the plants that create a beneficial, natural environment.

  Sunlight: in the external façade a system could be mounted that basically uses a glass ball that is filled with water to concentrate the sun's energy onto a PV panel. In this way the sun's energy is concentrated by up to 10,000 times [11]. The ball can also be rotated and would include a tracking system, meaning that energy collection is maximized throughout the day. The PV panels transport collected energy to the battery, which converts DC power

into AC power with the frequency and voltage corresponding to the requirements of electricity grid. The collected power could be used to charge the whole building and to operate lamps, which are physically similar to sunlight. It has a resemblance to the wavelength of light, the light intensity (about 10 000 lux) and color. Lamps are turned on when there is no sunlight outside which would provide the right balance of melatonin to the organism.

At the time of accelerated global urbanisation and climate change, performance oriented design has en increasingly important role to play. An expanded understanding of building performance acknowledges that all forces acting on buildings (climate, energies, information, human agents) are not static and fixed, but rather mutable and transient [12]. Future building envelopes should be responsive to both internal and external conditions. With the use of parametric and multi-criteria optimization tools, buildings envelopes can be designed to respond to the various requirements.

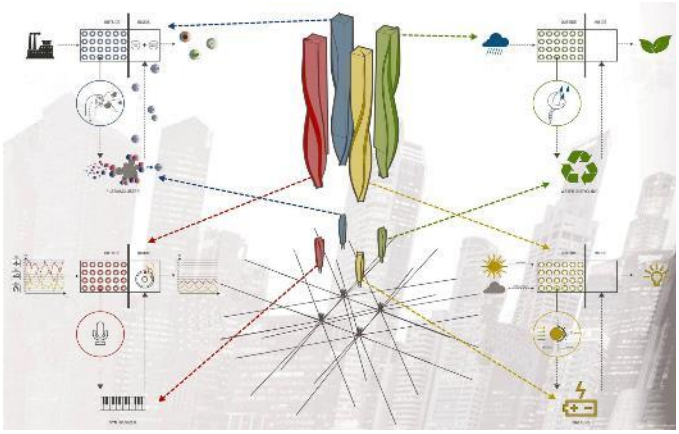

Fig. 8. Sylwia Gudaczewska, Piotr Orłowski, Processing external negatives into internal positives diagram

This is a proposal for a protective and adaptive building envelope. This is an idea of a first level operational framework for present and future investigations towards performance based responsive architectures through a set of responsive typologies. A mock-up concept of a secondary environmental system to a primary structural system joint into a collective behavioural system equipment with an artificial neuron network system is presented above (fig. 8-9).

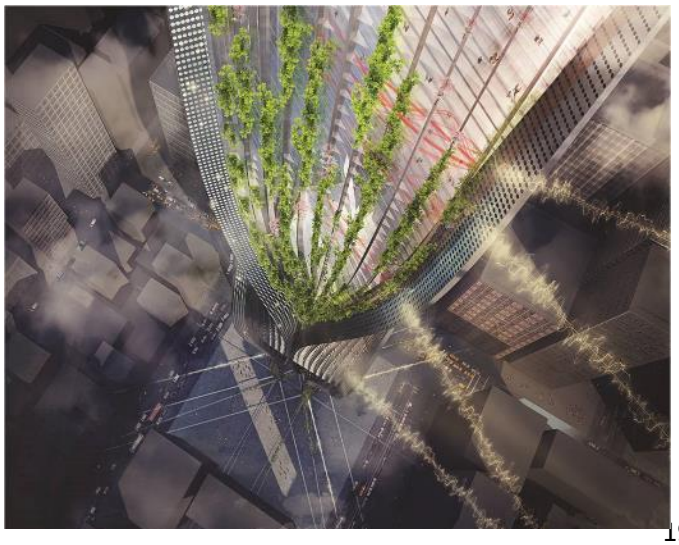

Fig. 9. Sylwia Gudaczewska, Piotr Orłowski, Protective human health envelope for a smart city under rapid development

Cities that focus on smart development have to seek innovative solutions and wisely manage resources in order to become a forces for economic development. Depending on the location and needs, the building (this could be a public or residential space) function could be combined for private and public functions. Buildings also could create networks with each other, such as a neuron network. In a big metropolis environment, stimuli can be very different in each part of the city. Some of the buildings could collect more water or sunlight for others that need it. In that case, buildings could contact each other by sending Wi-Fi information about the state of collected energy.

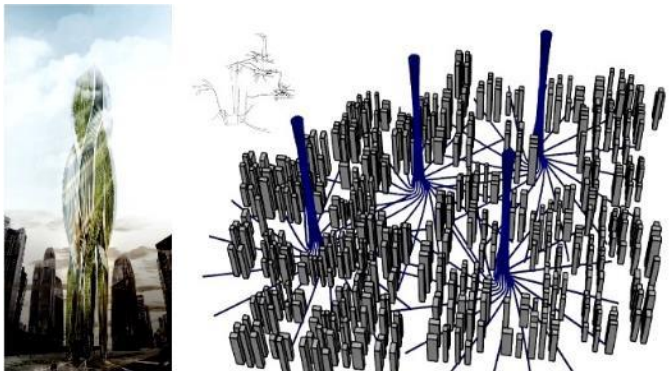

Fig. 10. Sylwia Gudaczewska, Piotr Orłowski, Buildings neuron network

Buildings, which would save more energy, could transmit it to those that need it, assuring a sustainable balance in the network (fig. 10). It would become a living part of the city, processing the external factors such as light, noise, smell and give it back into the building, creating different atmospheres of sounds, smells and other inputs, that the city creates every day. This design task can only be tackled by means of an integrated approach to planning, i.e. interdisciplinary collaboration between architects, facade and environmental engineers.

IV. DISCUSSION

"Nature's design is fluid, ephemeral, beautifully patterned. Nature's technology is dynamic, lightweight, and driven by a functional imperative - optimum efficiency" [13]. Nature uses life-friendly manufacturing processes. Nature uses an ordered hierarchy of structures. Nature fits form to function. Nature relies on self-assembly. The models provided by Nature have been an inspiration for building forms since time immemorial.

During the period of modern architecture, natural growth and evolutionary processes were described by Frank Lloyd Wright (1867-1959) who, learning from Nature, introduced the term "organic" architecture in which form and function were just one aspects [14]. This philosophy of architectural design, emerging in the early 20th century, asserting that in structure and appearance a building should be based on organic forms and should harmonize with its natural environment. Today, this term means produced by derivation

from living organisms, structures and it is borrowed from biology in architecture enabling designers to compare inorganic forms, structures and function to found in living organisms [15]. The root of this concept can be traced back to the aesthetics of classicism. At the same time, through sufficient observation of both naturally occurring and experimentally derived phenomena Buckminster Fuller (1895-1983) has discovered that a tetrahedron is the smallest and basic geometric element which Nature uses to build its forms [16]. He believed, if humans were part of Nature, all humans' creations must be natural as well. In order to create designs, as Nature does in its environment, it is important to understand what the emergence, natural form-shaping processes, are, and to know how to use mathematics to describe these processes in the ways which are useful to designers.

In 21st century, inspired by the biological evolution and morphogenesis of organisms, recent advances in the discipline of evolutionary computation propose a radically different approach. Currently, there is some exchange of ideas and techniques between architecture and other disciplines such as biology, physics, chemistry and mathematics to mimic the identified processes. The focus is mainly on natural processes of formation and adaptation which occur in Nature, on the instrumentalization of these processes through mathematical models and computational techniques, as well as on their simulations and digital visualizations. This approach named "morpho-ecological design" changes diametrically the ancient concept of imitations and mimesis within western tradition of aesthetics [17]. Learning from Nature is not only a mere application of biological knowledge to solve technical problems. Today, this is a much wider area.

V. CONCLUSION

The climate change oriented design is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's climate-cycle. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. However, one of the central tasks for architects is to provide opportunities for habitation through specific material and energetic interventions in the physical environment. Many of the efforts to reduce environmental problems in the construction sector address the issue in a simplistic way, since the methods being used ignore the need for a critical reflection about the cultural values of a consumerist society, based on a production system where capital assumes too much importance at the expense of moral values. The changes that will occur as a result of climate change over the next 10 years will have a huge impact on the lives of hundreds of millions of people. The climate change oriented design is a new term introduced to distinguish the multiparametric approach in the formation of architecture called "green". This architecture promotes differentiation of environmental conditions through a morphological intelligence, which promises not only a new spatial paradigm for architectural design, but also a far more sustainable one that links the performance capacity of material systems with environmental modulation and the resulting provisions and opportunities for inhabitation. Future building envelopes should be active to both internal and external conditions as well as should be act as a protector of human health.

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