INSTITUTE OF ART STUDIES, BAS

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ABSTRACT

FROM A DISSERTATION PAPER FOR CONFERRING A
PHD DEGREE

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THEORY AND HISTORY OF ARCHITECTURE, 5.7.

Supervisor: Assoc. Prof. Arch. Stela Tasheva, PhD

Reviewers: Corr. Mem. Prof. Arch. Atanas Kovachev, DSc

Prof. Joana Spassova-Dikova, PhD

Sofia, 2021

The Dissertation Paper was discussed and designated for public defense during a meeting of the "New Bulgarian Art" Research Group (part of the Fine Arts Department), held on July 08, 2021.

The Ph.D. thesis is 165 pages long, consisting of: an introduction, 3 chapters, conclusion and research contributions. The bibliography lists of references and internet sources include 11 titles in Cyrillic; 39 foreign titles (in English and German); 134 standalone web-based sources. Additional literature: 21 titles. After the references lists two more attachments are also included – "a brief dictionary of relevant contemporary architectural terms" and "Image Catalogue" (consisting of extra 105 pages with various photos and illustrations).

The public defense will take place on 30th November 2021 at 11:00 AM at a meeting of the scientific committee, with members: Corr. Mem., Prof. Arch. Atanas Kovachev, DSc; Prof. Joana Spassova-Dikova, PhD; Prof. Irina Genova, PhD; Assoc. Prof. Arch. Stefan Asparuhov PhD; Prof. Arch. Orlin Davchev, PhD;

The materials which will be used in the defense will be made available to all interested parties in the Administrative Department of the Art Studies Institute *at 21 Krakra Str.*

GENERAL CHARACTERISTICS OF THE DISSERTATION

Relevance of the study and research state of the topic.

Relevance of the study. The relevance of this study is mainly determined by the fact, that bionics and biomimetics(biomimicry) are young and dynamically developing interdisciplinary fields of science. The scientific significance of the topic is further confirmed by the presence of many nuances and intertwinement in terminology – the modern definitions of the listed concepts are fluid, they gradually and continuously undergo dynamic elaboration by a number of authors in different scientific spheres. Thus, the various interpretation proposals and complementary term-meanings induce branching out of the terminology in more specified categorization and clarifying concepts such as "technical bionics", "architectural bionics", "biostatics", "biomechanics", "bioenergetics", "bioinspired" design, "biomorphic architecture", "biophilia", "bio-utilization", etc. At the same time, the current development and the open for interpretation potential of the concepts lead to the need for their rethinking, eventual refinement and categorization.

In addition, the relevance of the doctoral research today is also being justified by the state of the cutting edge approaches for design and construction. State-of-the-art tools such as parametric design, combined with various technologies for digital fabrication and rapid prototyping, have not been as widely available for analysis and simulation in the recent past. Computer-aided design and manufacturing tools (CAD and CAM) provide growing opportunities for the development of the examined topic; for analysis and application of the studied principles on more than one level - from purely formal and mechanical, to structural, interactive and ecosystem level - especially in the context of interdisciplinary research.

The relevance of the research is also confirmed by its close connection with other key topics for the evolution of architecture in the XXI century such as: sustainability (sustainable architecture), eco-architecture (ecological design, environmentally friendly systems and natural materials in architecture), the concepts of parametric/algorithmic design, for automation and interactivity in architecture, for application of innovative "smart" materials. Last but not least, the present moment permits more clear assessment of the fact, that bionic and biomimetic research efforts even since the middle and end of the XXth century carry particular intrinsic social and regionally cultural features. They must also be rethought from a contemporary point of view, using the advantage of the historical distance and the new experience gained during the exploration of the topic. A notably relevant aspect in this sense is the study of the transformations of bionic principles, depending on different historical, locally

inherent and technological conditions (including in bulgarian environment), as well as their potential connection and intertwining with traditional techniques and materials and with contemporary architectural tendencies.

Research state of the topic. The study of the natural environment - its mechanisms, self-organization and adaptation processes – be it in animate or inanimate nature, has intrigued man since ancient times. The sensory responses to environmental stimuli gradually evolve into evolutionarily proven solutions, found in biological forms and natural processes. Consciously or not, the search for inspiration and answers in them leads to interesting visual and technological analogies between the first created "buildings" for human habitation and bird nests, beaver and termite structures, etc. Similar analogies are present in the works of Renaissance inventors such as Leonardo da Vinci, and later on, such artistic and scientific approaches and the manner and strategies of their application are constantly being upgraded. The term "bionics" was coined in 1958 by the American physician(MD) Jack E. Steele in reference to systems, representing natural or similar characteristics[1]. While the term "biomimetics" was coined in the 1950s by the American biophysicist Otto Schmitt and is associated with "the design and production of materials, structures, and systems that are modelled on biological entities and processes" [2]. In the second half and at the end of the XX century, these two concepts turned out to be widespread in a number of social and humanistic science domains. Synchronically and diachronically in time are appearing numerous related and complementary concepts, some of which already mentioned above. This rapid development testifies for the continuing and even increased scientific interest in the topic, which makes it even more broad and interdisciplinary. The generated terminology, in its diversity and elaboration, is traced and discussed in detail in the first chapter of this text.

In our modern times, the methods, related to bionics and biomimetics, are increasingly intertwined and strive for symbiotic relationships, both among the same and different fields of science. This is reflected in the evolutionary development of architecture and design - in the pursuit for contemporary volumetric solutions, artistic shapes and construction approaches, as well as for new types of habitation concepts, innovative materials and interactive systems. Increasingly pronounced interdisciplinarity in research approaches is present, also a multi-

[1]Julian F. V. Vincent*, Olga A. Bogatyreva, Nikolaj R. Bogatyrev, Adrian Bowyer and Anja-Karina Pahl. Biomimetics: its practice and theory, Department of Mechanical Engineering, Centre for Biomimetic and Natural Technologies, University of Bath, UK. doi:10.1098/rsif.2006.0127, Journal of The Royal Society Interface , Published online 18 April 2006, p.471.

[2] Oxford Dictionary, available at: www.lexico.com/definition/biomimicry, [last accessed 26.05.2019]

layered and even more in-depth analysis, and with all this - a wider deployment of methods and directions of their application is being observed. Over time, the design efforts through the prism of nature-inspired principles has undergone repeated conceptual development and manifested themselves on many levels and scales - from pure imitation of formal characteristics through innovative constructive, analytical and structuring, material and even ecosystem approaches, reaching to mechanisms, based on self-organization, adaptation and emergence. In combination with the rapid development of technology, opportunities open up for transition from utopian hypotheses to real experiments, which brings along respective social and cultural reflections.

Well known concept developments from the second half of the XX and the beginning of the XXI century, related to the bionic methods with regard to form-finding and subsequently to various other stages of architectural creativity could be listed. Such are the works of Y. Lebedev, C. Alexander, D.W. Thompson, Neri Oxman, Michael Pawlyn, Maibritt Pedersen Zari, Petra Gruber, Thomas Speck, Jan Knippers, Asterious Agkathidis, Achim Menges, Jenny Sabin, Philip Beesley, etc. Experimental and applied science activity in the field is actively pursued in some architectural research centers abroad (for example in ICD - Institute for Computational Design, Stuttgart; IAAC - Institute for Advanced Architecture of Catalonia, Barcelona; The MIT Media Lab, Massachusetts, USA, etc.).

It is important to note, that a number of architectural concepts and theoretical studies in Bulgaria have also been developed in the field of bionics and biomimetics – such as some specific scientific surveys; research projects, regarding modularity, sustainability and other aspects of inspiration and the link with nature, of adoption of its mechanisms and systems. Here could be mentioned also some bulgarian authors with regard to the examined topic such as: Asen Milchev, architect Matei Mateev, assoc. prof. architect Dobrina Jeleva-Martins, architect Rositsa Peeva, etc. In recent years, due to the development of the mentioned parametric tools for analysis and design in architecture, there are more and more conceptual developments in our country, even from student level on, influenced by biomimetic ideas. Bionic approaches were also the subject of a couple of other dissertations in Bulgaria. Such are, for example, the works of: Rangel Chipev, "Bionics in industrial design for interior and exterior", defended at the National Academy of Arts in 2013; also of Emilia Panayotova, "Natural forms and design. A systematic approach for building the living environment", defended in 2013 at NBU.

Object, Subject, Aims, Boundaries and Methodology of the present research

The **Object** of the research are bionic(biomimetic) approaches and strategies in contemporary architecture. Scientific and conceptual developments are being examined, as well as exemplary case-studies in selected architectural works by authors such as Frei Otto, Kisho Kurokawa, Sou Fujimoto, Santiago Calatrava, Shigeru Ban, Paolo Soleri, Nicholas Grimshaw, Antoni Gaudi, Ken Young, Neri Oxman, Michael Pawlyn, Maibritt Pedersen Zari, Matei Mateev, Asen Milchev, Rositsa Peeva, Milan Rashevski, etc.

The **Subject** of the dissertation are the transformations of the explored biomimetic methods and tendencies in the contemporary architecture. The emphasis is laid on contemporary manifestations, possessing an increased degree of innovation.

It is important to clarify, that due to the obvious lack of more significant historical distance, also due to the fact, that the terminology is still being actively developed and the research in the field of bionics and biomimetics is globally ongoing, most of the examined methods can be characterized as innovative in one or another scientific aspect. For intelligibility (and in accordance with taking into account certain tendencies), in the development of the dissertation it is defined, that the degree of innovativity can be considered as higher if the following generalized conditions are met (separately or simultaneously):

- more pronounced, distinctly increased characteristics such as these listed are present: inter- and multidisciplinarity, interactivity, efficiency, holistic properties (of analysis, directions of optimization, application of methods);
- qualitatively new combinations of architectural approaches and methods, resulting in their possible novel transformations.

The hereby formulated tendency for increased degree of innovativity can be traced in the extended categorization proposed by the author in the first chapter - the higher levels of implementation of the methods, as well as their combinations, correspond to higher levels of innovation. The employment of at least two levels of application of bionic approaches is also considered a prerequisite for increased innovativity[3].

[3] "levels of implementation" refers to, on the one hand, the following initial classification (according to Milchev, Asen. "Vnusheniyata na prirodata: Architekturnata bionika". Sofia, Narodna Mladezh, 1984, p. 19):
● *First level* – Imitating natural forms - only on a formal level
● *Second level* - Resemblance and adoption of constructive principles

Here it is also necessary to be clarified that the transformation of the methods means their upgrading and a kind of modification to some extent, resulting in increased multidimensionality and efficiency on several levels, with a pronounced positive aspect - not a complete transformation or negative direction of development.

The **Aim** of the dissertation is on the one hand - a renewed systematization of the bionic approaches and results in the field of contemporary architecture. In addition, characteristic transformations (of the explored principles) and their key features are outlined, as well as their potential interrelation with regional (and locally traditional) construction and architectural techniques and methods. Another goal of the doctoral research is to assess the possibilities for their transfer into Bulgarian environment, as well as to determine and evaluate possible directions for future development, transformation, general upgrading of the examined approaches and methods.

Considering the above stated, the following objectives are assigned to the study:

- To examine the development of key terminology and definitions in historical terms;
- To propose an update and clarifying extension of the classification of biomimetic methods and the corresponding levels of inspiration from nature;
- To outline the bionic and bio-inspired tendencies in the Bulgarian architectural practice;
- To systematize the combined application of biomimetic principles on two or more levels (with increased degree of innovation) - through analysis of world-renowned practice examples - and to seek out its relationship with sustainable architectural concepts;
- To study and summarize the concept of symbiosis(symbioticity) and to set a symbiotic criterion in architectural design;
- To formulate characteristic transformations and the transformative potential of certain biomimetic methods and approaches in architecture;
- To reveal combinations between tradition and innovation in architecture and to offer new opportunities for experiment, transformation and symbiosis in this sense and direction.

Respectively, the expected research results are mainly associated to the field of contemporary architecture, its history and theory.

● *Third level* - Research and optimization of the architectural entity as an organism or ecosystem;
also, on the other hand, refers to the extended classification, developed subsequently by the author, which is presented in detail in Chapter 1.

Scope of the study. The chronological boundaries, which confine the selected examined principles, encompass the last decades of the XX and the beginning of the XXI century (up to the present day with the current even more intensively developing innovative and experimental approaches in the considered area). Juxtapositions and single references to earlier periods are also available in order to clarify terminology and interconnections.

The research will not be limited geographically in terms of the examples used to illustrate various statements and evidence, due to the insufficient coverage of the topic, solely in Europe or Bulgaria.

The selection of the examined developments and concepts is also limited by the need to be met a number of set criteria such as - increased degree of innovation, as well as architectural value, determined by a number of factors (some of which aesthetic, functional, sustainable, ecological characteristics; distinct relationship and connection with the environment, two-way interaction (with the inhabitant), in some cases relation with traditional approaches and know-how, as well as with holistic principles of analysis and design; employment of bionic inspiration on two or more levels - in strategies for analysis, design, construction, etc.).

Methodology of the research. The research methodology of the dissertation includes: analytical review of literature sources; terminological systematization and synchronic analysis of scientific perspectives (when necessary also a semantic analysis of certain concepts); selection and evaluation of key projects and artifacts; comparative analysis of selected case-studies, according to their components, characteristics and structural relationships; experimental concepts.

Structure and content of the dissertation.

The doctoral paper consists of:

- Introduction, including the set basis of the research - relevance, research state, object, subject, aims, boundaries, methodology, pursued tasks and the respective expected results of the dissertation.
- Three chapters, including both a generalized review of known selected, reference systematizations and examples, as well as author’s classifications, approaches and proposals. They are developed as follows:

- **The first chapter** of the study is entitled "Chronological overview of terminology and definitions. Formulation of a degree of innovativity and a proposal for a new type of classification of biomimetic methods." Its first section examines chronologically the main concepts and approaches, that describe the topic – those notion's introduction and development, gradual unraveling of application levels. In the next, second section, their categorization according to various authors is laid out. A possibility is revealed - for a new type of extended classification of the explored methods of bionics and biomimetics in architecture, in line with the increasingly dynamic present development of the field, with its inherent multidisciplinarity and versatility. An approbation of the proposed classification levels is conducted through analysis of the dialogue between space and material (material "envelope") in architecture, in order to clarify these interrelations through the prism of naturally inspired analytical and form-finding methods (biomimetic principles and systems). The author's extended categorization of these methods serves as a foundation and framework for the selection of the analyzed examples and for the development of the following topics in the next chapters of the text.

- **The second chapter** is entitled "Bionics and bio-inspired tendencies in the Bulgarian architectural environment. Analysis of world-renowned practice examples. Interrelation with sustainable concepts." The first section focuses on the application of the examined methods amid Bulgarian environment - from tradition to contemporary concepts, complementing the historical overview of the first chapter. Once again, the analysis develops while taking into account comparison examples and trends from the world-renowned architectural practice. Therefore an assessment is performed - of the presence and prevalence of certain scientific interest, potential for development and also relation with parallel tendencies in architecture (ecological, sustainable, organic trends, as well as regenerative design, interactivity, parametricity, etc.). Opportunities for connection with traditional regional architectural and structural principles are discussed. The second section presents and analyzes leading examples of architectural projects and concepts falling within the parameters, described in the proposed by the author classification. The focus of the study are the examples, illustrating an employment of biomimetic principles, applied at a minimum of two levels (and respectively of a higher degree) – i.e. in which an increased degree of innovativity is present. In this regard are analyzed also the levels of bionic inspiration and implementation, concerning the potential for development and transformation of the said methods towards optimization, revitalization, sustainability, environmental awareness, interactivity, multidisciplinarity, increasingly pronounced holistic design, etc. In the last part of the section a juxtaposition is made with

other contemporary tendencies, that have a relation with the highest levels of application types, put forth in the classification, proposed by the author. Different approaches to ecological architecture and its connection with modern concepts of biomimetics in sustainable architecture are also presented.

- **The third chapter** is entitled: "Transformation and transformative potential of biomimetic methods in architecture. Symbioticity and author's criterion for symbiosis in architecture. New opportunities for experiment and symbiosis - a combination of tradition and innovation - discussion of hypotheses." In the first section an author's criterion for symbiosis in architecture is introduced. Subsequently, the options of its use are discussed - as an auxiliary tool for architectural design and research tasks, pursuing optimization analysis through a bionic prism (of the efficiency and general performance of architectural systems), as well as for research endeavours, aiming to determine potentials for new design approaches, for opportunities for innovative, experimental combinations with increased sustainable properties. The symbiotic criterion, proposed by the author, is tested in the analysis of selected natural materials (considering examples of both traditional and contemporary methods for their application) and to what extent their use can have such a character. The highlight of the second section is in the final discussion - "reflection on types and nature of possible transformations of traditional architectural techniques through bionic analytical principles and design approaches". Some possibilities are discussed, involving the plausible combinations of biomimetic and sustainable approaches for application of natural materials in architecture and their symbiotic and transformative potentials. Hypothetical alternative directions for development and design-thinking are proposed, which evolved through comparative analysis of selected reviewed examples. Those are namely the potential transformations, based on combinations of regional influences and innovative bionic strategies.

- **Conclusion** of the dissertation, which summarizes some main directions of concept development of the bionic methods, strategies and models and their transformations, revealed in the process of research and analysis. Some cultural and social reflections and repercussions of the biomimetic concepts in architecture are also outlined.

The expected results are in the field of contemporary architecture and its theory and include:

1. Rethinking the levels and degrees of application of bionic principles in the architectural design process;
2. Formulation of a new type of extended categorization of the examined principles in order to outline contemporary tendencies of development and research of potentials for transformation and innovation;
3. Structuring of data and examples from a specific Bulgarian context in order to perform comparative analysis and summary of results and to determine potential directions and opportunities for development, research, optimization;
4. Outlining the trends, steering the future development of the explored principles, their relation with other contemporary architectural concepts and the potential for transformation, based on the interconnection of both modern and regional (and traditional) techniques and architectural approaches;
5. Proposing new relevant directions for analysis and optimization, based on bionic criteria and along with that, discussing new opportunities for experimental transformations;

A potential novelty is the use of a modern prism to systematize the main methods, categories, approaches and tendencies in the field of bionics and biomimetics in architectural sphere. The study of their evolution, taking into account the transformations, imposed by regional specifics, also hasn't been explored so far and has a heuristic character.

I hope that this text will also contribute for new perspectives to open up for scientific studies and complementary future research on topics such as: tendecies for bionically influenced transformations in design-thinking approaches or design principles and strategies; transformation of traditional building approaches, based on bionic inspiration and analysis, aiming increased efficiency, sustainability and general ecosystem behaviour.

SUMMARY OF THE DISSERTATION

Chapter 1: Chronological overview of terminology and definitions. Formulation of a degree of innovativity and a proposal for a new type of classification of biomimetic methods.

The inspiration from natural evolution-based solutions is present in the architectural and as a whole, artistic endeavours of the human beings from the early stages of our history. This tendency, including in the field of architecture, is described with numerous terms, often with intertwining meanings, also considering the relation with complementary concepts such as “organic architecture”, eco-architecture, sustainable architecture, which emerge at different stages of the theoretical development of these notions, each defined by a variety of nuances and focal points.

The first chapter consists of two sections with several subsections.

The first section of the chapter is entitled "*Bionics and Biomimetics – a chronological overview of basic terminology and classifications".*

In its **first part** are presented and clarified *the terms bionics and biomimetics, derivatives of theirs and related concepts.*

The main objective of this section is to systematize certain aspects of the various viewpoints and alternative directions for architectural artistic and scientific research endeavours in this field (done chronologically – beginning with the introduction of basic concepts, and continuing with more recently coined ones and so, considered as newer to some extent). Fundamental terms are presented and reviewed and an overview of various definitions is offered – those, generally assigned to bionics and biomimetics (and other related terms such as "biomimicry", "biomorphic", "bio-inspired design", "biophilia", etc.) Along with this is presented the common nature of the research endeavours, that those encompass in general scientific terms and then is assessed how these relate to the field of architecture and design. An attempt has been made for their conditional systematization and categorization.

A well-known definition of bionics is: "the study of mechanical systems that function like living organisms or parts of living organisms" [4]. However, such formulation points the reader’s attention to the adjective "mechanical" and the particular imitation of a "function",

[4] Oxford Dictionary 2016, available at: www.lexico.com/definition/biomimicry, [last accessed 26.05.2019] A similar definition is found in the Bulgarian edition of "Dictionary of foreign words in the Bulgarian language" by I. Gaberov and D. Stefanova ("Abagar" AD, V. Tarnovo, 2002, p.96) - "A science for mechanical and electronic systems, which function in the same way as living systems or possess similar characteristics."

respectively, directs to more technological analogies. This turns out to be a common understanding, influenced by some of the more modern uses of the term in popular culture (referring to the film industry, with the movie “The Bionic Woman”, based on Martin Caidin’s novel “Cyborg”). Such definition proposal also self-limits the meaning, which partially differs from the initial concept, offered with the introduction of the term. That is why, the interpretation proposed by another distinguished dictionary - Merriam-Webster, back in 1960, could be determined as more comprehensive and accurate. It goes namely - "A science, concerned with the application of data about the functioning of biological systems to the solution of engineering problems"[5]. The term "bionics" was introduced in 1958 by the American physician Jack E. Steele - according to some authors – as a portmanteau-word from "biology" and "electronics". He defines it as the broader idea for "*the science of systems which have some function copied from nature, or which represent characteristics of natural systems or their analogues"* [6]. Later on, the Bulgarian author Asen Milchev offers an additional definition of this notion in his text, which is dedicated to the topic of bionics, but with an emphasis put on architectural applications: “Bionics deals with the study of bionic systems and processes in order to use the acquired knowledge to solve engineering problems. It can also be viewed as a study of methods for creating technical systems, whose characteristics are close to those of living organisms. This new science seeks to transfer to technology the best inventions of nature, *the most rational and efficient structures* that have evolved in the biological world over a course of a million years” [7].

Biomimetics (later followed with “biomimicry”), on the other hand, has almost similar meaning to the one, assigned to bionics as a broader, principle concept for the discipline. However, this term emphasizes the "mimesis" - the imitation - of natural mechanisms. Its definition is formulated in the Oxford English Dictionary as „The design and production of materials, structures, and systems that are modelled on biological entities and processes“ [8]. The etymology of the term could also be traced by the ancient Greek words βίος (bios) - life and μίμησις (mīmēsis) - imitation, mimicking. This term, describing the notion for transferring ideas and analogies from biology to engineering was coined in the 1950s by the American

[5] Merriam-Webster Dictionary, available at: www.merriam-webster.com [last accessed: 10.03.2018]
[6]Julian F. V. Vincent*, Olga A. Bogatyreva, Nikolaj R. Bogatyrev, Adrian Bowyer and Anja-Karina Pahl. Biomimetics: its practice and theory, Department of Mechanical Engineering, Centre for Biomimetic and Natural Technologies, University of Bath, UK. doi:10.1098/rsif.2006.0127, Journal of The Royal Society Interface , Published online 18 April 2006, p.471.
[7] Milchev, Asen. “Vnushenijata na prirodata: Architekturnata bionika”; Sofia Narodna Mladezh, 1984, p.6 (Милчев, Асен , „Внушенията на приорадата: Архитектурната бионика“)
[8] Oxford Dictionary 2016, available at: www.lexico.com/definition/biomimicry, [last accessed 26.05.2019]

biophysicist and engineer Otto Schmitt, who worked on a physical device in his doctoral research, that should mimic the bio-electrical action of a nerve (the so-called "Schmitt trigger")[9]. Some of the classic examples for implementation of biomimetics in product design are: the "velcro" - a type of fastening system for clothes and other products, inspired by a type of prickly plant; the "lotus effect", is used as a “hint” for surface properties development, used for self-cleaning paints and finishing materials.

In this part of the text are also presented and clarified a number of related and derivative concepts and principles that are directly connected or can be transferred to the field of architectural bionics and biomimetic design. Some of them are "mimesis" (in terms of art and art history), "biological aesthetics", "physiological aesthetics", the so-called "economical principle" (related to design approaches, allocating material for efficiency and minimization of stress concentration), "technical bionics", "architectural bionics", "biostatics", "biomechanics", "bioenergetics", "ecomimicry"; "biomimicry" (popularized by Janine Benyus with an emphasis on sustainability and ecological design), "biomutualism", "bio-inspired design", "biomorphic", "biophilia", "bio-utilization", "biornametics”, etc.

The performed review of the terminology, leads to the conclusion, that from a present point of view, bionics and biomimetics are often intertwined, complementary concepts and the derived from them principles could be applied to many fields of science, gradually changing their meaning and focus, depending on the context. They are implemented not only in the sphere of the medical and engineering disciplines, but also in scientific branches of economics, social sciences, computer science, etc. An example for this is the work of architect Christopher Alexander, in which he put forth his theory of the "fifteen properties in Nature" [10]. However, the focus of the present study is namely in the application of bionic methods in the field of architecture and design.

In this regard, it is important to clarify that, despite of the observed nuances of the terms’ meanings, in the following parts of the text, ***the adjectives "bionic" and "biomimetic" are used essentially synonymously, referring to the examined "methods and systems, found in nature."*** *Bionics and biomimetics also imply specific sensibility and behaviour to the environment, to the relationship between man and nature, animate and inanimate. Those notions foster an intended balance between technology and nature, and inevitably carry with them the respective social and cultural significance and repercussions.*

[9] Bhushan, Bharat. "Biomimetics: lessons from nature-an overview". Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences.,15 March 2009

[10] Alexander, C. A. The Nature of Order, Book One: An Essay on the Art of Building and the Nature of the Universe, Center for Environmental Structure, Berkeley, CA, 2002-2004. p.244-295

In the **second part** of the section is presented a *review of the levels of inspiration from nature in architecture and product design.*

Both in the more aesthetically and scientifically broad review of the terminology, and also focused in the field of architecture, could be traced the different levels of inspiration from natural forms and systems even from the earliest stages of the development of this idea. In architecture, the pursuit for the "perfection of nature" also begins with purely aesthetic and formalistic endeavours and gradually passes through a different spectrum of implementation and direction in order to reach innovative manifestations. The scale of the developments is also diverse - from large, urban scale, to detail, specific building systems, functions or material characteristics.

The architectural analysis of the inspiration from nature begins with the usage of floral and zoomorphic motifs as decorative elements in the interior and exterior. It is true that this type of aestheticization of architectural details through natural forms is too far from the understanding of bionic architecture today, but actually, the presence of such elements is not always purely aesthetically provoked. Very often the *symbolic* meaning of the ornaments could be the leading one. The section lays out the observation of seemingly cyclical pattern of the pronounced return to nature-inspired creative impulses on a different level and stage of the process of architectural design. Often such parallel tendencies appear in response to dominating movements (historicist ones), and eventually also to the seemingly excessive "mechanization" or the consequently emerging strict, "unnatural" living environment - the mentioned modernist concepts of proportionality, derived from human nature, collide with form-finding strategies, ensuing microclimate and "architectural biotope" in rupture with that primary source of natural inspiration.

The analysis continues through a contemporary point of view, discussing the notion for the "form as a diagram" - then and now, as well as the observed blurring the boundaries between the physical, digital, and biological realms - accompanied by growing, comprehensive digitalization, interactive ("smart") systems and materials, and also the "new modularity"[11] of parametric and algorithmic design. However, the increased computational abilities of the emerging digital tools for design and fabrication and the naturally subsequent opportunities for much easier achievement of complex parametric forms, sometimes results in the intensification of some quasi-biomorphic trends. On the other hand, even with the purely

[11] "New modularity" is an expression, used by the author in an article for the bulgarian magazine "Architektura, referring to some of the novel parametric approaches for design, that could make unification strategies partially obsolete. (Tsekova, Nona. "3D-printing and the architectural education in Bulgaria", issue 5, 2017)

mechanical, indulgent introduction of natural forms or biomorphic nuances into the aesthetics of a design, one should not underestimate the creative effort for experimenting with such still unconventional method of form-finding, which inevitably leads to new typologies of architectural spaces and respective ways for their realization and habitational utilization.

The in-depth study of natural mechanisms, forms and systems (including the mentioned computational level, but not only) leads to tendencies for expand implementation of bionic principles on more levels. These potentials for employing the methods not only as biomorphic inspiration in various forms, both in the design process and subsequently in the very "life" of the architectural object and its complementary environment are presented in the texts of architect Yuri S. Lebedev, where the first introduction of the term “architectural bionics” takes place, presented as a subdivision of the “technical bionics” [12]. The hinted connection of the biomimetic strategies with the ecological side of the architectural design could also be found in the analyzed texts of Asen Milchev. Therefore, the biomimetic principles are considered not only as a source for inspiration for formal (aestethical) and structural improvement, but also on a larger scale - as a method for achieving more "animate" interconnection between environment and architecture - with an emphasis on the balance between technology, nature and a healthy microclimate, pursuing the development of efficient eco-sustainable human habitats.

In the modern dynamic world, the intertwining of seemingly distant fields of scientific research is observed more and more often. The ancient tendency for narrow specialization and scientific "segregation" is gradually changing its direction, pointing to new and unexpected intersection possibilities. Architecture and design as an integral part and valuable building block for vital social and cultural aspects of human life, become involved in this tendency for intertwining of seeming opposites such as ecology and technology, “back-to-nature”-strategies and synthetic (material-)programming. The great potential of bionics and biomimetics and their constant development is largely due to this multidisciplinarity, which connects unexpected fields of science, thanks to the high potential for divergent interpretation of the principles derived from nature. Such intertwining leads to opportunities for new perspectives and alongside to new directions for solving existing and emerging problems. They could be related not only to purely architectural tasks (aesthetic or functional), but also to many more globally important topics such as environmental awareness, quality of life, resource efficiency, economic trends and in general the human behaviour to the environment.

[12] Lebedev,Yuri. Архитектурная бионика [Architekturnaia bionika], Стройиздат [Stroiizdat], Moskva, 1990

The **second section** of the chapter is entitled "*Degree of innovativity of the bionic (biomimetic) methods in architecture - a proposal for extended categorization. Analysis of the dialogic pair "material-space", performed through a bionic prism – approbation of the proposed classification."* It presents the proposal for an extended classification of the examined methods of bionics and biomimetics in architecture. Leading illustrative examples of architectural projects and concepts, falling within the parameters described in the proposed classification are analyzed.

The **first part** of the section presents a *summarized review of systematizations of bionic principles and methods, offered by distinguished authors in this field.*

The topic of bionics and biomimetics undergoes dynamic development - concerning the study approach, the application of existing solutions and the search for new ones; the increasing degree of "scientific idea-synthesis" in the bionic sphere. The levels of analysis of the natural components and the resulting rediscovered valuable relationships between living organisms and the architectural environment, as well as the layers and principles of implementation of the studied approaches are constantly being upgraded. *This part of the text reviews some proposals for systematization of bionic principles (relating both methods of architectural bionics, and also nature-inspired design in general), outlining the course of development of the bionic approaches and the contemporary most promising directions of scientific research, in particular related to the field of architecture and design.*

Selected classifications of the bionic methods and approaches are presented, which could be combined and further elaborated by introducing “concept-penetration” levels (or ways and degree of application of the adopted from nature principles) - from single-layered implementation to complexity; from static to dynamic; from one-sided direct transfer of ideas to pursuit of adaptability and interactivity, from mono- to multidisciplinarity.

In the **second part** of the section is developed and presented the author's proposal for *extended categorization of the bionic approaches in architecture.* This is performed after analysis of listed exemplary case-studies and data-summary, taking into account the mentioned possibilities for concept-combinations. An emphasis in the author’s proposal is the monitoring *of the levels of implementation of nature-inspired principles, the increase in the degree of complexity, as well as the observed tendency for growing interactivity, multidisciplinarity, holistic and more active interconnection with the environment (the ecosystem).* In short, in the categorization are laid out the following levels (accompanied by relevant examples at several planes and at a different scale):

1. **First level of implementation of bionic approaches**

   (directly used pattern/principle only on one plane)

   - only formalistic inspiration from nature is observed – i.e. pure biomorphic approach;

2. **Second level of implementation of bionic approaches**

   (directly used principles on several planes)

   - inspiration, concerning not only shape and appearance, but also function, structure – employing mechanical and structural principles, found in the living organisms or the natural environment as a whole;

3. **Third level of implementation of bionic approaches**

   (interactivity in principles used, relating to structural/environmental properties changes)

   - inspiration from interactive models, applied to complex, gradient and interactive architectural and design systems and installations; utilization of electronics, smart materials, meta-material, etc. - with variable behavior towards changing conditions, loads, environmental stimuli, complex property variability; possibility for incorporation of smart-functions such as "self-cleaning", "self-repair", etc. (but again still only *interpretation* of natural mechanisms and systems is present);

4. **Fourth level of implementation of bionic approaches**

   (interactivity in principles used, relating to environmental conditions and design elements, with incorporation of "animate media" and/or "evolution" to the system)

   - the level is upgraded, compared to the previous one, considering observing of even *higher multidisciplinarity*, potential element of *self-learning, evolutionary development of the system/structure and symbiotic characteristics* – the interactivity is again found in the behaviour towards the environment, in synergy with the surroundings, but this is achieved through *applying a "living" system or components*; there are concept proposals, that intertwine biological components or materials with a technical system or product - using not only the principles but also the bio-matter itself; that experiment with "living" materials, structures and systems, which, as an active component of the system, not only interactively change their behaviour, but can also evolve over time, improve the state of the system, etc.

The proposed author's categorization aims to systematize some aspects of the diverse new perspectives and alternative directions for architectural research in the field, reflecting the intertwining between sensory and visual, biological and technological, static and interactive, tradition and innovation. The levels of implementation, formulated in the classification, point towards the increased potential for detection and activation of the so described innovativity and transformation. They could be traced and conceptually validated in the analysis of various

elements of architectural design and in the process to contribute for the achievement of even more multi-layered analysis. An example for this is the subsequently presented analysis of the interconnection, the "dialogue", between architectural space and material (material envelope).

Respectively, in **the third part of the second section,** the categorization proposed in the previous part is tested through the *developing of extended classifications of the relations between material and space through the prism of certain bionic models and principles.*

The dialogue between space and material envelope, presented in terms of the specifics of the architectural environment, has the potential for diverse and dynamic relations and effects. Its analysis is not a novelty in architectural theory, but the original value of the research endeavour lays in the attempt to clarify these relationships precisely through the prism of nature-inspired analytical and form-finding methods - bionic principles and systems. Thus, a corresponding extended classification of the relationships between material and space is put forth, refracted through the prism of some bionic models. This is performed with focus on the employment of biomimetic methods in the design phase. The corresponding analysis of the described material-space dialogue is carried out, following the levels of the categorization, earlier proposed by the author and on two planes - once in terms of the materials used and secondly - in terms of the architectural space and its organization.

In the presented classification from material point of view, the level of implementation for a given bionic principle is traced mainly through *the way of use and organization of the considered material.* Those relations between material and space could be formulated in two main planes. The first utilizes a previously presented classification by architect M.P. Zari, which mainly reflects on the scale of application of biomimetic principles in the project[13]. Secondly, this simplified systematization could be elaborated based on the proposed by the author four levels of implementation of biomimetic principles - from a purely formal level to the fourth level – defined by interactivity, multidisciplinarity and symbiotics.

Given the listed basic analysis planes, several types of relationships between material and space in an architectural environment are considered. In the process, they are linked to criteria such as "tectonic characteristic of form-generation", "permeability" of spaces and materials ("membranes"/"barriers" in the architectural “organism”) "ecosystem reciprocity", "emergence", etc. In the full text of the dissertation these levels are unraveled and accompanied with relevant justifying architectural examples.

[13] Zari, Maibritt Pedersen. Biomimetic Approaches to Architectural Design for Increased Sustainability. - IN: SB07 New Zealand Paper number: 033, Sustainable Building Conference (SB07), Auckland, New Zealand, 2007

The next classification - from space perspective – is to a certain extent built on a heuristic principle. It aims to add to the proposed construct of levels of implementation of biomimetic principles, as the trace of the applied bionic principle is monitored by focusing on the second component of the examined relationship - space (its evolution in terms of scale, perception, activation potential, habitational utilization, dwellers' "feedback" and interplay). The analysis is again conducted on several planes - concerning the development of the understanding of architectural space; the type of the spatial system; the guiding directions for organization and optimization of the space, etc.

The examined interrelations between material and architectural space eloquently outline the different levels of implementation of contemporary biomimetic principles in the complete process of architectural design and construction - both as a mere inspiration, concerning shape or structural studies and organization, but also in more complex approaches, referring to holistic systems-design, parametric design, evolutionary optimization of design. This observed build up tendency is directly related to the transformative processes, associated to the bionic design methods. *The author's extended categorization for the implementation of biomimetic approaches, conceptly tested through the analyzed interrelation, could be defined as one of the author's contributions in this doctoral thesis, but even so, its introduction and elaboration had to find its place in the first chapter, as it serves as a foundation for the research analysis in the next parts of the text. The following topics are developed, using as framework the thus determined levels of implementation of bionic methods and principles, helping to concentrate the research endeavours in the desired scope - namely related to the higher levels of implementation of the examined principles (and/or combinations of them on different planes and scale), with a pronounced degree of innovativity in their combinations and tendencies for transformations.*

Chapter 2: Bionics and bio-inspired tendencies in the Bulgarian architectural environment. Analysis of world-renowned practice examples. Interrelation with sustainable concepts.

The second chapter consists of two sections, the second of which has three parts.

So far have been presented and summarized the terminology and tendencies, referring to bionics (and biomimetics) in a global perspective, including the conceptual transformation, taking place at different levels of analysis and employment of the explored principles.

The first section, *entitled "Bionics and bio-inspired tendencies in the Bulgarian architectural practise - from traditions to contemporary concepts",* focuses on the Bulgarian context, taking into account the terminology and interrelations already clarified in the previous chapter, as well as in line with the structure of the proposed by the author systematization for upgraded levels of implementation. The exploration is again chronologically organized - from past to present examples. The goal of this part of the text is to establish and outline *whether and in what form are present manifestations of biomimetic methods and approaches in domain of architecture and design in our country.*

In Bulgarian context, the biomimesis could be observed in the architectural creative impulses of man since the Middle Ages, and is again explored at different levels. Therefore, examples are offered beginning with the early stages of nature-emulation, used as an artistic principle in the decoration of various elements from both Revival period and even earlier architectural examples in our lands. The analysis continues through representative cases for incorporating natural shapes in architectural form-finding design-methods in Bulgarian context dating back to the second half of the XX century. Thus, notable biomorphic projects from the Bulgarian practice are presented, such as the project for an exhibition pavilion of Bulgaria at Expo-70 in Osaka by architect M. Mateev. Other projects of his are also mentioned, where he applies next levels of analysis and imitation of models, found in nature. Another project with bionic inspiration analyzed in the section is the so-called "Biohabitat-2000", which is also dated to the 80s of the XX century. It was created by a group of students under the guidance of architect Pavel Dochev and engineer Krastyo Krastev. Interesting aspect of it is that the holistic approach, pursued in it, is currently an intrinsic part of the higher levels of implementation of biomimetic principles and despite the then futuristic note to some of the proposals in the project, from today's point of view they seem quite modern and feasible - for example the interactivity of the building envelope, as well as the energy self-sufficiency and smart-control of the microclimate are key topics, considered in contemporary architecture.

The interrelation of bionic principles with modern tendencies for "green" and eco-architecture are examined in more detail in the next sections of the text. However, in this particular part are listed also some Bulgarian examples, which could be related to main features of this type of architecture, namely *healthy microclimate, minimizing the negative environmental footprint of buildings, energy-efficiency improvement and even interactive connections and behavior.* Zero-energy and passive construction is gaining more and more popularity in Bulgaria. Although the corresponding project examples in our country have not yet reached such a strong conceptual connection with biomimetics, as in a number of known sustainable concepts, in this

section are presented such architectural developments from Bulgarian practice, which after all are considered as bearing logical connection with certain bionic principles.

Thus, examples in this context are listed, as the study of architect Milan Rashevski on the topic of "bioclimatic variations", that encompasses analysis of Bulgarian traditional architectural examples (from Revival Period) and their variations, assessed in the context of various energy efficiency models. The mentioned tendency for "interactivity" of the building behavior is also noticed in some of the other projects of the architect, achieved through "smart" systems, that respond to changes in the environmental conditions (and provide feedback). One of the most recent projects of that kind, discussed in detail in the section, is the so-called InDeWaG (Industrial Development of Waterflow Glazing-Systems), developed in a large multidisciplinary team[14]. The project's concept for high-tech modular glazing, with circulating water in the chamber between the glass planes of the glazed unit, is directly related to the earlier mentioned contemporary notion for interactivity of the facade cladding. Their innovative idea for responsive control of the building overheating, turns the facade into an active part of the building organism, even with an element of adaptation and increased environmental awareness in terms of energy and resource efficiency. That is why this example finds its place in this review of bio-inspired tendencies in Bulgarian environment. Further to this, other examples for responsive behavior of the building-envelope in the context of ecological architecture are discussed in the section. Some scientific theoretical developments are also mentioned - such as those of Assoc. Prof. Arch. Rosen Savov[15] and Assoc. Prof. Arch. Dobrina Zheleva-Martins. She examines namely the architectural form as "a part of the universal form-generation in the world" and in this regard develops a typology of shapes and spaces [16] .

The inspiration from the natural form-finding methods, based on the unity of function and structure, on the natural mechanisms and systems, interwoven into the general form, leads to further works, evidence for the interest in the bionic design principles in Bulgaria since the 1980s. In this context, is presented the diploma project of architect Rositsa Peeva (supervised by Prof. Arch. Ivan Sazdov) for "Complex Educational and Cultural Center". The architectural project is based on a "cellular" system of pentagonal modules, which vary in size and functionality, but whose choice is determined by considerations of energy-efficiency and microclimatic interrelation between function and shape -generation. Other more recent projects

[14] Available at : http://indewag.eu/ [last accessed: 15.11.2019]
[15] Savov R., Architecture as biomimetics, 6th International Scientific Conference "Architecture, Construction - Modernity" 30 May -1 June 2013 Varna, Bulgaria
[16] Jeleva-Martins, Dobrina. Tectonics as a theory of form and form-formation, "Prof. Marin Drinov" Academic Publishing House, Sofia, 2000

of hers are also listed, which attest to her continuing and growing interest in biomimetic morphological, structural, systems-related principle applications.

In an even more contemporary context, its traced how the potential for unity between structure and form unravels in contemporary architecture in the tendecies for parametric architecture. Among the Bulgarian studios contributing even at the research level in the domain of algorithmic design, inspired by biomimetic principles, is mentioned studio "Morphocode" and the software plug-in they develop - "Rabbit", which is being used for more intuitive analysis of various natural models and mechanisms. The rapid development of the digital technologies allows for experimental design and even conceptual prototyping endeavours in biomimetic direction even from a student level. As an example of this is presented one of the student projects of architect Desislava Chusheva, for "A place for recreation, suitable for park and urban environment", in which again natural mechanisms serve as inspiration in the solutions of various design tasks. Another example of the growing surge of interest in the biomimetic theme in architecture as well as among university environment (again in relation to the development of digital technologies) is the course "Algorithmic Methodologies in Architecture", led at UACEG, Sofia, by architect Zlatko Yanakiev, and also lectures and exercises from the section "Bionics and Synergetics", in the discipline "Form-Finding", developed by Assoc. Prof. Arch. Dobrina Jeleva-Martins at the UF, Sofia.

In summary, the trace of inspiration from nature can be observed in Bulgarian architecture from the past, up to the present moment, both in the intuitive and the later intentional structuring of the architectural environment, adopting ideas from natural mechanisms, systems and form-finding principles. The deep understanding of natural structures, combined with the accelerated development of digital technologies for analysis, design and fabrication brings along more and more experimental and more complex aesthetic, structural and functional design results, which could already be observed in Bulgarian environment. Only at the higher implementation levels of bionic approaches – those characterized with employment of interaction and responsive components, there are for now much more limited examples in Bulgarian context. However, the increased interest both in the field of materials science (“self-repairing” and other types of “responsive” materials), digital fabrication and parametric design, as well as in the domain of “smart” building systems, energy-efficient and eco-tendencies, leaves fellow architects and designers with hope and in eager anticipation of their new bionic manifestations in our architectural environment. The elaboration in the levels and planes of analysis and application of methods takes place on a relatively smaller scale, compared to global tendencies, but the existing respect and inherent

bond to local architectural and building traditions designates potentials for intriguing combined models and innovative directions for transformation of the novel methods of bionics and biomimetics in architecture. In this regard, it may be noted, that due to the many years of experience and traditions in the use of natural materials such as clay, straw, wood, etc. in architectural practice in Bulgarian setting, there are prerequisites for a *hypothetical interrelation between traditional architectural methods and contemporary bionic applications of natural materials in combination with sustainable and symbiotic features.* These characteristics, as well as their positioning in the higher levels of categorization of bionic implementations, are discussed in detail in the next chapter.

The second section of the chapter covers *an analysis of contemporary concepts and projects, results of worldly recognized expertise - combined application of biomimetic principles at two or more levels - with an increased degree of innovativity.*

This section designates representative examples of architectural projects and concepts that fall within the chosen parameters, set in the systematization proposed by the author. The focus of the study is on the examples that refer to the higher ones of the proposed levels - namely those, that imply application of bionic principles at two or more planes (concerning not solely shape, function, etc.). An overview of concepts and examples from the practice of selected leading architects and researchers in the described field is offered - architect Michael Pawlyn and architect Neri Oxman.

In **the previous chapter** is introduced the notion, that in contemporary architecture are being formed more and more interrelations between bionic and sustainable architectural tendencies. This section also examines some fundamental sustainable concepts that have conceptual similarities with the higher levels of implementation of biomimetic principles in order to formulate a combined scheme, illustrating the relationships between the various interaction "components", that build and influence the “architectural organism”. *The summary of the examined interrelations will serve as a basis for further development of the analysis for the place of natural materials in the explored bionic approaches, for their symbiotic potential and significance as a crossing point between traditional and contemporary innovative architectural approaches.*

The first part of the section presents and analyzes some concepts and projects of *Neri Oxman’s work as exemplary for the implementation of biomimetic approaches at the level of materials engineering and its relationship with form-finding (concerning the application of the principles to the highest levels described in the first chapter - with the incorporation of interactivity).*

The research endeavours and case-studies of the architect and designer of Israeli origin - Neri Oxman, can be related to the highest and experimental, often even futuristic levels of research and application of biomimetic principles (often also linked to "speculative design"). Her architectural projects and scientific developments pursue innovative design approaches with bionic inspiration – they are an impressive example of the higher, third and fourth level of biomimetic design implementation. In a number of them is observed the mentioned state-of-the-art tendency for combination of bionic approaches with "bio-assisted" systems. This concept aims precisely an increase in efficiency and responsiveness. The section outlines a detailed gradation in the project-concepts, which illustrates the direction of idea-transformation and the increasing prominence of characteristics such as multidisciplinarity, interactivity, evolutionary optimization and "vividness" (incorporation of “living” bio-components into structures and systems).

Inspired by the mechanisms in nature, by the natural processes of form-generation of matter through self-organization and growth, N. Oxman seeks and creates new form-finding methods and practices, not by firstly setting the shape itself, but by developing a "process" for its formation - new digital fabrication tools and specific technologies that link parametric design, digital fabrication, biological features and the surrounding environment, with their intrinsic materials as an integral (material) dimension of the design process. In this approach, "material precedes shape, and it is the structuring of material properties as a function of structural and environmental performance that generates design form"[17]. Design is seen as a paradigm, defined not by the desired form, but by aimed behavior. Architect N. Oxman combines material engineering with architectural design on a variety of scales. Her projects possess different degree of interactivity and multifunctionality, achieved by translating function into form through high-technology solutions. The leading characteristics of the target results are also always determined by contextual and ecological principles of design - architect Neri Oxman introduces the term "material ecology". The described in the section gradation of the implementation of the examined bionic principles is evident for the reaching point of a stage in the design and construction of the architectural environment in general, in which *there is a grand blurring of the lines between the animate and inanimate, natural and artificial, biological and synthetic.*

Highlights from the doctoral research of architect N. Oxman are described, which are also a starting point for a lot of her subsequent projects, where the ideas undergo further elaboration. The gradation is observed on many levels - both in main conceptual focus -

[17] Oxman, N.,“ Material Computation“, Making and Prototyping Architecture, AD Reader, 2012

gravitating between contemporary art, "speculative design" and architecture, as well as in project scale and technological solutions. In the beginning the projects are to a great extent merely inspired by nature (the exhibitions “Designing the elastic mind”; “Imaginary Beings”), later on they are shaped, based on mechanisms adopted from nature (Fiberbots, processes for 3D-printing of remaining concrete formwork, etc.) reaching to such, being built through and enhanced with the help of biological components (Aquahoja Structure - biodegradable material based on biopolymers - chitin, cellulose, pectin). The build-up in the combination of design and fabrication approaches reaches a stage where the biological elements have a leading role in the form-finding and construction - they are presented as "designed by nature" (Silkpavillion 1 and 2). Nature is perceived not only as a "mentor", but also as a "participant" in the process of generation of form and structure or of functional improvement and symbiosis between “living” and “non-living”. According to N. Oxman, the final stage of this development would be a reversal of the paradigm in the somewhat futuristic "design-inspired nature", i.e. shaping or influencing nature itself through design - design together with and for nature itself (Wanderers Project; Vespers Series). The interdisciplinarity, which is inherent for these higher levels of the proposed classification is also a leading feature of her research work - the fields of parametric design, digital fabrication, ecology, materials science and even synthetic biology are intertwined.

In order to outline more clearly the described gradation - of new forms and functionalities, interactivity, complexity - in the next part of the text are presented in more detail some of the mentioned projects (both from her portfolio, as well as team projects from the Mediated Matter group, led by her in MIT). The projects’ concepts build up from *bio-inspired*, through *bio-designed*, to *bio-evolution* through design. This process of “design-evolution” also triggers the need for new methods for design and construction - a combination of "top-down" modeling of a project-framework and "bottom-up" principles and design procedures for form-generation - both physical and digital. They are clear evidence of how digitalization in design has reached such a stage of development, allowing for high spatial resolution and material complexity - both in form-finding, as well as in fabrication.

In conclusion, industrialization and mass production promote modularity in architecture, narrow functional specialization of the elements, and so draw the path of modernist architecture to the state of internationalization. However, this "modernization" in the production mechanisms in architecture is also beginning to carry with it some negatives - increasing anonymity and disconnection from the particular environment, natural and social context. The approaches, developed by architect Neri Oxman and her team aim to focus onto

the opposite - mass "personalization" of designs, reactivating the "live" connection with the given context and its specific functional and performance related requirements. The desired structural characteristics and attitude to the environment are considered as leading factors for the concept-generation. The result is often "formal, structural and material heterogeneity" [18].

Biomimetic approaches in materials science more and more often are preferred as a strategy for the development of innovative high-performance materials with a minimized environmental footprint. Neri Oxman's projects are just one example of the organic intertwining of materials science and architecture into a collective bionic result. Other examples of contemporary material inventions include bioinspired dry adhesives, lightweight and highly durable biomaterials, inspired by plant structures and based on cellulose (Tuula T Teeri et.al.), biosteel, "liquid wood" (Werner Nachtigall) and many others, which then find application in a number of architectural projects and often even have a qualitatively decisive role for their main idea.

The **second part of the section** presents *Michael Pawlyn's concepts and projects, referring to the ecosystem approach in biomimicry (involving the relation with sustainable and ecological notions in architecture, systems analysis, closed loop model, regenerative design in architecture).*

Michael Pawlyn is a British architect, world-renowned with his work in the domain of biomimetic architecture, with a focus on sustainability, environmental awareness and innovation. In his idea-developments is noticeable a direct influence of the theoretical constructs and design guidelines, described by the previously mentioned Janine Benyus, in which she emphasizes the inherent potential of biomimetic approaches to render increased, multidimensional eco-friendly, sustainabile characteristics on many levels. According to architect M. Pawlyn, the employment of evolutionarily proven biomimetic approaches also pushes towards eco-strategies and sustainable design, based on the promotion of main principles such as *adaptability, a closed loop model of resource and energy usage (compared to the efficiency of linear models), alternative renewable energy sources (like solar economy)* and various ecosystem models of *organization of architectural and natural environment in symbiosis.* The urge for overcoming of resource constraints can and does stimulate innovation, and there are a vast number of examples in biological models on how to adapt to such constraints. According to the architect, this is the most significant connection between bionic architecture and humans - as a way in which it can affect their social environment, culture and

[18] Oxman, N.,“ Material Computation“, Making and Prototyping Architecture,AD Reader, 2012

quality of life, because biomimetic models are able to have regenerative effect both on the environment and with it, on its inhabitants and on different economic models.

The analysis of the listed anchor points of Pawlyn's concepts and case-studies, highlights his understanding of biomimicry as a notion *that primarily aims to focus on sustainable and functionally optimized solutions - on issues related to resource efficiency, sustainability and environmental constructs, implementing closed-loop models, rather than exclusive use of materials from biological sources.* Transdisciplinarity, regenerative change, synergy and a holistic approach to environmental challenges in general are of central importance for these processes. Accordingly, he often speaks of mimicking an ecosystem, and its mature relationships (symbiotic ones), but often by the use of mainly high-technologies. The next step would be not only mimicking, but also recreating an ecosystem or developing one, with its inherent basic features and functionalities. An assessment is made, considering how the described key strands of ecosystem thinking can be applied to the field of architecture at a range of scales, from urban and infrastructural to building units.

Projects with the participation of architect M. Pawlyn are reviewed, each of which relies on biomimetic approaches in the design process, in order to achieve optimization, efficiency and synergy from functional to ecosystem level. Each project also showcases the desire for a complete rethinking of basic architectural paradigms, in order to be transformed through ecosystem and bionic thinking to more regenerative and environmentally friendly behavior for achieving balance with both the environment and its inhabitants. Thoroughly presented project examples are *"Eden Project" (2000)* - one of the landmark projects, illustrating his biomimetic concept; *Sahara Forest Project (SFP)* - an example for adaptation to limited resources; The Biomimetic Office (a collaboration project with Arup R&D and the renowned professor in the domain of biomimetics J. Vincent), The Mountain Data Centre, The Biomimicry Museum, which also reveals multi-dimensional bionic inspirations, but also in combination with approaches, based on the culture and traditions of the Middle East. From the presented architectural concepts and projects it is evident that the principles, derived from nature, could serve as an inspiration, matrix for analysis and "recipes" for solutions and improvements on many levels - from form-finding and structure, to environmental awareness, resource efficiency, overall interrelation with the natural surroundings and "culture of life". It is also important to note that the apparent inclusion *of local cultural design-inventions and developments* in the architectural analysis, part of some projects, is influenced by M. Pawlyn's shared understanding that the indigenous cultural environment is an often overlooked resource in the context of "modern" construction and that "vernacular architecture and low-tech local

traditions may offer solutions to diverse problems, working in tandem often with higher technologies"[19].

The last part of the section provides *a detailed comparison with some contemporary architectural tendencies and constructs, that have conceptual similarities and thus logical relation with the highest levels in the proposed classification.*

The analysis of the projects and ideas of the authors, presented in the previous two sections points to the growing tendency towards multidisciplinarity and holistic design in the described higher level of implementation of bionic approaches in the field of architecture and design. The projects reviewed in detail illustrate how the inspiration from nature could have a variety of dimensions and complex manifestations - in the processes of analysis, design and even real-world product fabrication. All of them share the common characteristic of a distinct focus on sustainability and striving for ecological sensibility in terms of environment and resources - materials, energy, attitude to the surroundings, fabrication, etc. Biomimetic principles are logically linked to human's relationship with the surrounding environment - both natural and "artificially created", architectural. This connection is traced in the constantly changing usage nature of the latter, its maintenance, restructuring and adaptation to new cultural and social models. *This creates the natural need in this section to be analyzed some concepts for ecological architecture and their connection with contemporary models of biomimetics implementation in sustainable architecture. The section examines how these trends are complemented or supported by bionic methods, where transformations of initial approaches are also being observed, and in what direction.*

The "green" or "eco-" architecture is defined by the leading concept of environmental awareness and the pursuit for minimization of the negative impact of buildings on the natural surroundings. The notion of "ecological design" is advocated in more and more disciplines (both architecture, as well as urbanism, materials science, product design, even agriculture, etc.) and in the broadest sense encompasses guidelines for creating a setting and processes, which support its ecological, cultural and social context. In architecture in particular, these demands are pursued through efficiency and moderation in the selection of materials and the energy use in construction, as well as in the organization of the created spaces and the role of the architectural object in the ecosystem as a whole. It must work with and for the benefit of his surroundings, not against it. There are many definitions of the essence of the increasingly used term "sustainable", but one of the most frequently cited is the one given by the so-called "Brundland report" - "sustainable development is one that meets the needs of the present

[19] Pawlyn, Michael. “Biomimicry in Architecture”, Riba Publishing, 2011, p.145.

without compromising the possibility to future generations to meet their needs." In general, and in the context of architecture and construction, the term addresses the need for increased attention to the efficient use of resources, impacting the environment and the quality of life. This interpretation aligns the concept of “sustainable” with the already mentioned “green” and “eco-“ design approaches. A number of the projects reviewed so far clearly show how some researchers are proclaiming the so-called “regenerative” design as the next “higher” step in this direction. It promotes not only process efficiency, but also on possible restoration of the ecosystem - of resources, energy, recyclable and environmentally friendly materials, better organization and reuse of waste, etc.

Natural patterns and models have evolved to enrich and sustain the ecosystem, which is as necessary to them as they are to it. This is achieved through maximum efficiency in form, material and structure generation - maximum functionality with minimal usage of material and energy, with recyclability and adaptability. Therefore, the inspiration and imitation of models and mechanisms, observed in nature, should be a serious prerequisite for acquiring sustainable characteristics in the final product - subject of architecture and design. Michael Nosonowski, for example, comments in a report on cultural implications of biomimetics and the perception of the "living”, that it brings a new perspective to engineering tasks, thereby promoting better harmony between man and nature[20]. *This leads to the assertion, that biomimetics is to a certain extent definitively linked to ecology, considering the pursuit for more environmentally friendly and harmonized with nature solutions - respectively to the concept of sustainable design.* However, some researchers believe that the link between biomimetics and sustainability cannot be sought reductionistically, only at the level of form- and structure-concepts, but also at higher, holistic levels of model imitation[21]. The certain critique comes from the need for a comprehensive analysis of the subsequent stages of the "life-cycle" of the designed object - namely such as fabrication/construction, as well as behaviour to the environment and its influence. *This fact defines the notion that inspiration from natural models is more clearly linked to sustainable principles if it is employed at more levels - reaching to stages of ecosystem analysis, adaptability and responsiveness (according to the proposed classification - these are again the levels above the second). A shift is also needed in the cultural perception of nature – to be viewed upon not only as a source of resources and inspiration, but also as a teacher and assistant.*

[20] Nosonovsky, Michael.“Cultural implications of biomimetics: changing the perception of living and non-living“, MOJ Applied Bionics and Biomechanics, Volume 2 Issue 4, 2018
[21] Reap, J., Baumeister, D., and Bras, B. Holism, biomimicry and sustainable engineering. In Proc. of International Mechanical Engineering, Congress and Exposition (IMECE), USA, 2005.

In this line of thought, it is not surprising that some of the contemporary concepts of biomimicry in architecture are tied notably to the theme of environmental awareness and sustainable design. Since the beginning and the middle of the XX century there has been a complete change and reversal of the paradigm for the human-nature relationship. The observed shift begins with the desire to “conquer nature", goes through attempts to preserve it, and finally reaches to the pursuit of a kind of "reconciliation with nature" [22]. The emphasis is set on the harmony between man and nature, which in turn leads to the emergence of new areas of research and disciplines such as "eco-design" and "holism". The emergence of biomimicry can be seen as part of this tendency.

The concept of a design principle, based on an ecosystem approach is also not a new one. In such case, the holistic systems-analysis and the inspiration from models and characteristics, observed in natural ecosystems provide main guiding principles for the design process. In this regard, the section presents in detail an well-known related term – the so called “Permaculture”, which as a notion promotes a system of principles with such focus. It designates the useful collaborative interconnections between system components and the importance of synergy of the final design – i.e. emphasizes the significance of the relationships between the elements. Numerous specialists in the sphere of “green” and “eco”-movements in architecture have gradually elaborated and developed their ideas for architectural sustainability with the use namely of biomimetic principles and approaches for design and analysis. In this context are explored some design strategies and known concepts for sustainable architectural models, in which a distinct bionic inspiration is found in one direction or another. The divergent accents in the employment of biomimetic inspiration provide the opportunity to compile a complex scheme, illustrating the potential for combination and complementarity of the models.

At this point is referenced the already reviewed concept of architect Michael Pawlyn for the application of biomimetic and sustainable principles, on an ecosystem level, which further “upgrades” the Holmgren and Molison's "permaculture"-ideas towards an ecosystem approach, which is based on biomimetic principles and directs them to the domain of architecture and urbanism. The second architect whose vision of eco-harmony between architecture and nature is presented, is Ken Yeang. The main focus in his concept is the integration of "ecosystem metabolism" in the design process. Ken Young's ecosystem approach is determined by pursuit for balance between biotic and abiotic (“organic and inorganic mass”), as well as between the behaviour of the building and the surrounding local specifics - climatic and cultural. Both of

[22] Pawlyn, Michael. “Biomimicry in Architecture”, Riba Publishing, 2011, p.143

the listed architectural strategies suggest that buildings (or urban habitats) can be viewed upon as whole ecosystems, in which "animate" and "inanimate" elements interact. In this entanglement of interrelations, in the integration of "synthetic" and "natural", symbiotic relations can be found and even designed at a different scale and parts of the dialogic connection "human - environment (micro- and macroclimate) – architecture (design)“. The third concept, related to sustainable architecture with bionic inspiration, which is added to the combined model-scheme, is "Building Biology". This discipline studies the holistic relationship between man and his living and working environment. The focus of the analysis turns both inwards - to the microclimate of the created architecture, as well as to the interaction with the exterior environment. In this concept in noticeable, that there is an accent on the use of natural materials and the created microclimate, in comparison to the previously mentioned two concepts, but does not fully include the ecological and sociological aspects of the ecosystem-oriented approaches described above. Another term that is taken into account when organizing the combined scheme is "material ecology", introduced by architect Neri Oxman. The extended interpretation of the term encompasses precisely the improved relationship between natural and man-made habitats, through bionically inspired fabrication and computational algorithmic form-finding.

The combination of all these innovative for their time sustainability notions and criteria gives a picture of complex relationships, that could be analyzed in both directions, again in a “closed loop”: (material - material); (material - human (inhabitant) → microclimate); (material - environment → ecosystem). *The resulting closed dialog model is visually represented by graphical diagrams.*

In this proposed by the author unified model, combining the concepts briefly presented so far, the analysis of the biomimetic principles in sustainable architecture can be focused namely on this more complex relation between material-human-context or how this could be analyzed as an actual foundation for "symbiotic relationships". In support of this possibility, the next chapter offers a criterion for "symbiosis" in architecture. Based on it, it will be discussed how natural materials fit into this ecosystem scheme of models, relationships and behaviour. A summarizing aspect of the discussion is how through their analysis, employing a given bionic prism, could be outlined the opportunities for transformation of traditional architectural techniques, in partnership with biomimetic methods.

Chapter 3: Transformation and transformative potential of biomimetic methods in architecture. Symbioticity and author's criterion for symbiosis in architecture. New opportunities for experiment and symbiosis - a combination of tradition and innovation - discussion of hypotheses.

The third chapter consists of two sections, each with two subsections.

The examples presented and analyzed in the second chapter clearly substantiate the statement that the application of bionic principles can be superimposed at many levels and stages of the design process *in order to achieve optimization, revitalization and maximum utilization of certain benefits of given materials, structures and processes.*

The third chapter introduces an author's criterion - *a criterion for symbiosis in architecture* - and discusses the possibilities of how it can serve as an auxiliary analysis tool, aiming to induce an increase of the efficiency and behavior-optimization of the overall architectural system (in accordance with certain bionic principles). Its use in the research process could also serve as a matrix, defining points of interest, with potential for employment of new design approaches, also suggesting innovative and experimental combinations and transformations, pursuing (symbiotically) increased sustainability. In particular, special attention is paid to natural materials and to what extent their application may have such a character. This is traced from traditional to modern concepts of their implementation. The combination of bionic and sustainable principles, regarding the usage of natural materials in architecture, could lead to interesting symbiotic results and transformations in the ways of material application, in order to improve the characteristics and performance of the created architectural system and environment. Some opportunities for the described transformations, as well as the respective transformative potential of the biomimetic methods in architecture are mainly presented and explored in the final discussion in the chapter.

The first part of the first section clarifies *symbioticity as a concept in architecture*, and in the **second part of the section** is introduced the author's criterion for *symbiosis in architecture*, which is subsequently is test-proved by examples.

In the previously presented combination of models, not only the specific "participants" are important, but also the type of interrelations, that emerge between them. Again, synergistic features are observed. In order to highlight the bionic "nonlinearity" in this model, the possibility of defining a "symbiotic relationship" is being discussed. This promotes the development of the said criterion for symbiosis in architecture, based on its well-known prototype equivalent, which we are witnessing in the natural environment.

The concept of symbiotics/symbiosis/ in architecture can be considered from several points of view - all of them, however, are inevitably related to topics, such as environmental awareness, sustainable design and holistic design. "Symbiosis" is a familiar term, commonly used in the domain of biology, but it has also been used in the field of architecture. It is mentioned by architect Kisho Kurokawa in relation to the metabolic movement, but in a more philosophical and sociological sense. He connects it with "hybrid architecture - in which elements from different cultures coexist in symbiosis." The analysis of the concept is also conducted through a biological semantic prism. Several different types of relationships are outlined, which, when introduced into an architectural context, have a grading significance for the evaluation of the final result or its effectiveness. Different types of symbiotic relationships in nature and their classifications are described and commented – such as the three main types - *mutualism, commensalism and parasitism,* as well as other types of classification (obligatory or facultative, endo- and exo-symbiosis, etc.).

By moving the analysis away of the biological framework of definition and classification and focusing on the functional expression of the relations, *several main types of symbiotic relationships* are found, which are defined by the author as “providing of protection” or “providing of maintenance” in exchange for “securing optimum/proper living conditions (environmental characteristics, food, mobility etc.). In short, these relationships could be labeled as “service vs. service” or “service vs. resource”. All those general types for relationship classification could be correlated to the architectural and design context. Also, the observed symbiotic relation could be observed, analyzed and later on designed on different levels of interaction :

- material – material (structure);
- material – human/ living conditions / microclimate (inhabitant relationships);
- material – (natural) environment (on a larger scale – urban scale - ecosystem);

The described generalized symbiotic categories and the levels, designated by the author are semantically united and find graphic expression in a respective original scheme, offered by the author.

Therefore, in an architectural environment, the elements in question must conform to the described "generalized functional expression of the relationship", so as the so-called "symbiotic relation" to be rendered as active. At each of the levels described above, the interrelations could be complementary defined, taking into account some of the already reviewed other classificational types of natural symbiosis. The symbiotic property of a material or component must be evaluated holistically and comprehensively at all of the levels

listed. The desirable result of such relationships may be found namely in the targeted programming, "cultivation" and optimization of ecosystem attributes.

Based on the developed criterion and as an approbation of the potential opportunity it offers for assessing the effectiveness and optimality of interrelationships in the architectural organism up to the ecosystem level, the place of some natural materials in the discussed bionic relationships is subsequently explored. Natural materials (such as wood, straw, clay, etc.) are traditionally used in architectural design for a number of reasons such as accessibility, healthy characteristics, frequent possibility for reusability, etc. All these qualities are today again linked to sustainable design principles. Examples are being analyzed in which are observed current tendencies such as introducing new technology degrees in the utilization of traditional natural materials, employment of new approaches for their implementation (often in direct connection or inspired by tradition), as well as even introduction of new experimental materials. The latter is observed both with materials that are high-tech, in terms of extraction and application - like in the presented case-studies of architect N. Oxman, as well as in such examples of newly discovered applications in architecture - like the bio-materials based on the mycelium.

In the second part of the section follows the approbation of the described concept of *symbioticity in architecture, by using the introduced criterion in evaluating the behaviour and possibilities for improvement of certain characteristics of the implementation of given natural materials in the architectural environment.*

Natural materials are invariably present in traditional building techniques, both regional for Bulgaria and in other parts of the world. Their application has also undergone a number of transformations, influenced by modern construction approaches and methods. As seen in some of the concepts of sustainability in architecture discussed above, natural materials are often integral or qualitatively complementary components of such strategies. In this part of the dissertation, some natural materials are examined namely in order to position them in the context of a transition from tradition to contemporary application, and subsequently as a part of the theme of pursued engagement with given bionic characteristics and principles of implementation.

Before proceeding to the specific analysis, a framework that defines certain materials as "natural" is set, as well as their relationship to the examined biomimetic approaches. Building materials of natural origin are generally considered sustainable, because of their local and often more ecological characteristics, but should also be analyzed in the context of biomimetics and their participation in the ecosystem interrelations, *within the larger*

framework of regenerative and holistic analysis in the human-architecture-environment relationship. Regarding the biomimetic approaches in architecture at ecosystem-level, not only the individual elements, but also the interrelationships and mutual influences between them are of great importance. Therefore, the implementation of such materials must be examined holistically, as a part of the overall architectural system and interrelationships with other elements – *taking into account the potential to participate in a symbiotic model for the analysis of the architectural organism.*

The following part of the text addresses the already mentioned transformation in the application (from functional and aesthetic point of view) of some fundamental traditional materials such as straw and clay. *The implementation of these materials in architecture can be inspired by traditional building techniques as well as by bionic ideas.* After a general overview of the characteristics and bionic potential of the materials, they are also holistically analyzed in terms of behaviour and reciprocal relation both to each other, the environment and in terms of symbioticity. To this end, an approbation of the symbiotic criterion introduced by the author is conducted, again through these few examples of architectural application of natural materials - straw and clay. They are analyzed at three levels, as proposed with the introduced criterion: M-M (material-material); M-H (material-human); M-E (material-ecosystem).

Based on the proposed criterion and levels of analysis, positions could be identified, where the performance and efficiency of a structure, combination of materials, architectural system could be enhanced - to initiate a new type of transformation based on a link with bionic methods of analysis, symbiotic relationship and design-principles or materials with a bionic characteristic. The analysis of the symbiotic potential of the materials on several levels of the architectural organism also allows assessment of the sustainability and optimality of their behaviour, as well as of the opportunities for improving their role and performance in a given architectural environment.

The symbiotic assessment of the described interrelationships is relevant to the optimization of many features such as - adaptability; relationship with the environment and bioclimatic performance; ecological and wholesome influence on the inhabitants and users (general conditions related to the quality of life as well as their monitoring and maintenance); sociological significance and impact (not only the use of local materials, also the use of local labour, a “vivid” relationship with the architectural environment in two directions - maintaining the environment and the ecosystem, preserving traditional techniques and with them the intangible cultural heritage).

The tendency for transformation of traditional techniques and approaches to contemporary applications is also observed among other natural materials, especially in the finishing works of the construction. In addition to traditional materials, in vernacular and contemporary applications, it is also observed a desire to bring an even more "alive" element into the architectural organism. This tendency has become evident in the presented Oxman's projects, concerning a development of hybrid biopolymers with embedded bacterial cultures and programmed symbiotic behaviour. Mention may also be made of some "modern" materials of natural origin which are considered experimental - for example, mycelium. *The discussion on the contemporary application of the explored and other natural materials in architecture with bioclimatic and sustainable qualities, also in a Bulgarian context, is continued in the next section. This is necessary in view of the following outlining of possible directions for transformations in the bionic principles discussed so far, also including a combination with the pursued "symbioticity".*

The **second section of the chapter** *discusses the transformative potential of the biomimetic methods.* The author *reflects on possible types and nature of transformations of traditional architectural techniques through bionic analytical principles and design approaches.* Hypotethical directions for such concepts are proposed. **The first part of the section** *describes characteristic features of certain construction techniques (and materials) and determines aspects and characteristics with potential for optimization through such transformation.*

A distinctive transformation in several directions is noticeable right from the overview (presented in the first chapter) of the bionic principles, analysis dimensions, inspiration and development. It can be observed at different levels, some of which are: *scale, functionality, concept orientation and elaboration, etc.* These directions of transformative development are briefly summarized in the conclusion of the thesis. *While in this section, a hypothetical case of one of the aforementioned transformations is proposed as a continuation of the analysis in the previous section - this is considered as one of the main aspects of this dissertation.* The chosen case-study relates both to the spheres of design process and the construction process, *as it is based on a intentional bionic in nature transformation in construction techniques, inspired of traditional ones.*

The choice for an in-depth analysis of this particular type of a possible transformation is largely justified by two main reasons. *On the one hand, because of the demonstrated above high potential of certain natural materials* - traditional and innovative - to take a defining and meaningful role in the higher levels of a bionic approach, characterized by *ecosystem-thinking*

and interactivity. And on the other hand, *especially in Bulgaria*, there is both the presence of many traditional architectural techniques with preserved high qualities, as well as a growing research interest in them. This is defined not only by the desire to preserve them, which is required for restoration works, but also by their *targeted evolution in contemporary architectural objects.* This topic is a major focus of the works of a number of fellow architects in Bulgaria, some of whom are arch. G. Georgiev, arch. Varvara Valchanova, arch. Veselin Veselinov, arch. Milan Rashevski, ASEM (Association for Construction with Natural Materials), the studios BUDA-Architects, HomeNest, Sponets, Barbali, etc. A brief review of Bulgarian architectural examples is conducted, highlighting the potential for transformation of the traditional building practices mentioned, as well as their harmonization with specific biomimetic strategies. The points of view of the cited Bulgarian specialists are also in clear alignment with the discussed biomimetic design principles in the concepts of regenerative systems, contextuality and closed-loop resource model of arch. Michael Pawlyn and Janine Benyus.

The above-mentioned case of transformation of traditional techniques could be described as an *"evolution" of the design-process through recombination, aiming increased adaptability, efficiency, and sustainability.* It can be monitored in the context of both Bulgarian traditional building techniques and of other analogues of theirs, united by one of the main materials used - clay. The symbiotic criterion presented in the previous section could be applied from the level of material analysis. In the presented analysis of the clay, carried out on the three levels (M-M, M-H, M-E) the potential for symbiotic optimization of clay is explored in relation to a couple of main characteristics: 1) structural stability; 2) overall material protection (against compromising by adverse weather conditions). *It is important to note that such "functional optimization" of the material is most optimal when it does not contradict or diminish positive relationships in the other levels (M-H, M-E). Therefore, the holistic examination is of a paramount importance for the overall assessment of the efficiency and environmental performance of the structure.* To confirm the few defined feature points, regarding which the material may benefit from directed “symbiotic” intervention, the conclusion is collated with general analysis of the fundamental architectural characteristics of the “earthen materials”. The many advantages of clay or “earth” in its unfired state are discussed in comparison with some basic weak points in its properties as a building material and the corresponding basic “pathologies” in architectural objects, built with a given type of “earthen technique”. Specific approaches to overcome the described "problematic characteristics" through corresponding architectural details and recommendations are also outlined. The proposed solutions are

always in direct relation to the respective climate. Consequently, the “earthen architecture” is also characterized by different behaviour and possible final shape and structural expressions, depending on the local environmental and climatic conditions. This characteristic is valid for most architectural objects, conceptually defined by a leading framework of material qualities and constraints. Different methods are explored, aiming minimization and overcoming these constraints to a certain extent, which is pursued both through standardly applied recommendations, but also by “contemporary upgrade” of traditional architectural approaches.

Different types of such strategies are discussed, and of main importance for the analysis are the described impressions of the author's participation in an architectural seminar and workshop, tutored by architect Anna Heringer. Her understanding of valuable architecture is directly related to achieving ecological balance and taking advantage of local natural and human/social/ resources, which is also done in the best and most environmentally friendly way, as well as being inspired by local cultural specifics, indigenous craftsmanship and building techniques. The described key points of the material characteristics define two basic form-finding approaches. They are explored and visually presented during the architectural workshop through scale models, which represent the differences between these two main types of acceptable in terms of shape expressions of earthen architecture, depending on the climate in which it will be situated. The author shares their distinguishing characteristics and so identifies options for creative interpretation of some constraints, turning them into opportunities for innovation and optimization. The introduction of innovative strategies and transformation in the process of application of traditional methods gives more flexibility in terms of construction time, possible building periods, constraints in terms of climatic conditions, maintenance, structural features.

The second part of the section *discusses a proposal for transformation with possible bionic inspiration.*

The summarized analysis and data so far confirm the relevance in seeking optimization regarding the two points raised: 1) structural stability; 2) overall material protection. *A discussion is proposed, addressing the possibility of designing a targeted combination, which aims to improve the behaviour of the "earthen structure" – assessed from a holistic point of view - in order to intensify the bilateral (mutualistic) symbioticity, to achieve overall improvement of the behaviour and efficiency of the structure (and material combination) at multiple levels (M-M, M-H, M-E). Bionic approaches would facilitate such optimization - from the stage of analysis and to the next level - of materiality and structure generation.*

In the first place is discussed, a possible replacement of the materials, used for erosion control layers (“water stoppers”), designated in the full text of the material-properties-overview – with another material, possessing more pronounced sustainable and even bionic characteristics. *One option for such kind of a possible participant in a designed symbiotic pair with clay could be mycelium*[23]. Therefore follows a brief overview of mycelium as an experimental building material with natural characteristics. For the sake of comprehensiveness of the discussion of a hypothetical symbiotic relationship between the two, the same holistic analysis is performed for mycelium as for clay in the previous section. The implementation of mycelium as a representative of the group of natural materials in architecture (also illustrated with a number of illustrative examples) is still at an experimental level, but its microclimatic characteristics are promising - non-toxic, sound- and thermal-insulating, moisture-, mold-, and fire-resistant, recyclable, etc. - as well as its potential for symbiosis and adaptability with the architectural organism. Of course, probably possible is also a more singular and intentionally programmed symbiotic relationship, involving development of a specific material, that could be designed to meet the given requirements for both performance and sustainability with bionic inspiration. However, this would require multi-disciplinary scientific research (as illustrated in the listed material-focused design solutions of architect Neri Oxman).

As stated above, mycelium is still a novel experimental material for application in architecture and design, but its advantages arouse the interest of researchers *also in Bulgarian environment.* With relevance to this topic are mentioned a couple of exemplary names such as the ecologist Assen Nenov, followed by a description of his professional interest into the topic of mycelium. Another presented project, originating in Bulgarian environment, and also focusing on mycelium as a main material, defining the concept, is the initiative of arch. Atanas Enev and his multidisciplinary team (together with Prof. Albert Krastanov and other specialists) - BioMyc, which deals with the development of mycelium-based products, such as packaging, protective parts for the auto-industry, etc. Examples, both from world-renowned practice and from the Bulgarian environment, show there is an active interest, concerning the potential of mycelium-based experiments to provide an ecological alternative for a range of materials, combined with the added value of the reuse-oppotunities of waste products (such as food production residues and agricultural waste, natural textile or even pla-plastic waste – all of which could be used in the process of mycelium production).

[23] According to the Merriam-Webster dictionary, mycelium is "the mass of interwoven filamentous hyphae that forms especially the vegetative portion of the thallus of a fungus". available at: www.merriam-webster.com, [last accessed 28.06.2019]

Therefore, taking into account the thus presented properties of this experimental material and designated techniques for erosion control of "earthen construction" (with "rain-stopping" layers), ***the author proposes a hypothetical symbiotic combination - clay+mycelium - as a possible transformation of the traditional "rammed earth" building technique, in order to optimize characteristics and performance of the architectural element through a symbiotic relationship with another natural material – the construct is again represented by a graphic diagram***. The ecological advantages of the so defined idea for material-combination are also discussed - compared to outlined alternatives such as cement, baked ceramics, bitumen, etc., as well as the potential for improving the overall performance of the architectural organism on ecosystem scale - through the symbiotic interrelations - mycelium could also actively participate in improving the microclimate, the insulation properties, the overall efficiency, could allow for more optimal modularity in construction and design methods, etc.

An alternative direction for possible symbiotic optimization with bionic inspiration is also discussed. It suggests the research potential of the idea of plausible improvement of the resilience of the "earthen" architectural elements to climatic influences - *by inducing "natural" surface crystallization.* Such processes are considered a hot topic being investigated by a number of researchers in the realm of biomimicry, which are developing projects, focused on self-healing of materials such as concrete and natural stone. Relevant research papers and concepts are cited. Based on the presented case-studies and projects, the author offers for discussion a hypothetical symbiotic relationship between earthen structures and such bacterial agents, which can cause "crystallization" of the clay surface, in order to form a protective film, that would aim not an activation of a "self-healing"-process by material cracking, but rather a "prophylactic" protection “layer” against erosion processes. Follow-up topics, concerning the extent to which the clay (earthen mass) is a suitable medium for the growth of such bacteria, as well as how such a mechanism would affect other material properties such as moisture permeability and compressive strength may be of interest for future research endeavours.

As a result of the above considerations, two hypothetical transformation-concepts and a new combination of materials have been suggested, aiming increased efficiency, improved performance and sustainability characteristics of the architectural structure. These assumed possibilities for enhancing the overall material and structural behaviour through a symbiotic relationship with another element are in the realm of hypothesis (based on comparative analysis – parallel between existing scientific data from conducted studies). The practical feasibility of such combinations has the potential to be explored and proven. For this purpose,

however, it is mandatory to be conducted a research with a multidisciplinary team and a prototype model to be developed (which can be tested in practice).

The final discussion on possible transformations of traditional architectural concepts with the incorporation of bionic models and principles does not exhaust the topic, but sets a starting point for new directions of research - both at the theoretical and practical level. Through this, is marked the great emerging potential of bionic approaches and alternative directions for design-thinking, the potential for qualitatively different strategies in employment of approaches, inspired by traditional building methods - in the process of their optimization and their translation into contemporary architectural environments.

Conclusion of the dissertation.

It summarizes the contemporary transformations of the bionic (biomimetic) methods and approaches in architecture. Some socio-cultural reflections and repercussions of these bionic concepts are also briefly presented and future topics with potential for development and multidisciplinary research are identified.

In addition to the proposed above hypothesis of a specific case of transformation of traditional architectural approaches with bionic inspiration (illustrating the transformative potential of biomimetic methods), the conclusion summarizes also certain main lines of research development and transformation, determined in the process of analysis.

The transformation tendencies of the bionic methods, principles, and research endeavours in terms of their nature and application types are summarized and analyzed in several cateogories, depending on the general expression of the transformation:

- in terms of design-thinking and design-process (with sub-themes – *concept-shift from design of a product to design of a process, the tendency for "recycle, reuse, reduce"* in the design-process, as well as the *concept-transformations in the design-processes even since the level of architectural education*).
- in terms of construction process - of types of methods (as direction; as a sequence, steps; as material awareness, sensibility and significance; considering leading tendencies to move from technological to ecological innovation, etc.), scale, degree of multidisciplinarity, etc.
- mutual transformation between bionic concepts and other architectural tendencies and movements is also observed (such as parametric architecture, sustainable architecture, traditional building methods).

These different tendency dimensions can be categorized and somewhat traced through the classifications for levels of implementation of bionic principles analyzed and introduced so far. In the gradation of the described levels is visible in the foreground an essential transformation in the areas and scope of application of biomimetic approaches and their corresponding physical expressions and results. Beyond this, however, a tendency for transformation can be defined in other parts of the creative architectural process. The advancement of computational technologies and scientific research methods allows for the incorporation of bionic principles and mechanisms in analysis, design approach, simulation methods, form-finding, optimization, rationalization. Not only the particular transformation of the principles themselves in terms of scope and means of application is evident, but also their influence on various elements of the architectural creative process. The parametrization of the design-process can be perceived as a kind of transformation of the implementation-approach of some bionic methods, but since there are a large number of generative algorithms that are based on natural inspiration, either apparent or veiled, parametric design especially in the field of bionics can be seen as more of a refinement and digitalization of some methods (which are originally based on algorithms, observed and extracted from nature). *That is, generative design is not considered as a result of a transformation, but as an auxiliary tool for its realization.*

A common aspect of the explored transformations is also briefly presented, considered as a key trait, that may direct to new fields with potential for research - the cultural and social reflections of the bionic concepts in the architecture. For an adequate socio-cultural assessment of the influences of these strategies a greater historical distance is required, as their development as concepts and terminology and their actual theoretical elaboration as principles and nature-extracted models began mainly after the mid-twentieth century, and even more actively only in the preceding one or two decades (especially with the advancement of digital technologies). However, despite the lack of the necessary historical distance there is a notable emergence of some more distinct tendencies and socio-cultural repercussions. This can be traced both in the present XXI century, as well as in relation to certain historical “styles” and architectural concepts, again linked to bio-inspired design, mimicking natural principles, but preceding or accompanying the moment of terminology introduction in the XX century. The socio-cultural side of biomimetic influences in architecture has a very broad scope, with several superimposed layers of artistic and philosophical nature. All of them are logically connected with topics, revolving around the relationship and attitude of the human towards the surrounding environment (both natural and man-made) and the way he builds upon it and utilizes the architectural “habitat”. *These are fundamental topics such as*

environmentalism(environmental awareness), resource efficiency, quality of life, regenerative design, socio-economic trends, etc. The amalgam of the natural and architectural environment could be very determinant for both the quality of life (with the micro- and macroclimatic conditions, the spatial and aesthetic characteristics it creates), as well as for the "culture" of life, the relationship with nature and the social contacts, mechanisms and trajectories for development, which are encoded in an architectural environment – across variety of scales- from urban level to architectural detail. Despite the mentioned complex multi-dimensional nature of the topic, in order to achieve comprehensiveness of the research analysis and the formulated above overview of summarized transformation-categories of the examined methods, it is important to highlight some main tendencies, which are accompanied by relevant illustrative examples. Some of them are related to the already mentioned research and development directions towards environmental awareness and sensibility, *in which is observed the mentioned shift from a desire to "conquer nature", through attempts to preserve it, to a quest for a "reconciliation with nature"*[24]. Another presented tendency, that has been described by some researchers, is how the emergence of biomimetic methods, both for analysis, design, as well as for prototyping and fabrication, has affected the human perception of what is "living" and what is "non-living", making it more difficult to distinguish between "natural" and "artificial". Purely aesthetic aspects that have socio-psychological implications (related to perception and sense of comfort) are also mentioned. As such could be defined - the promoted change of the attitude towards the surroundings - creating an emotional connection between architecture and the observer/dweller. In all of the examples is present also another significant meaning, that biomimetic approaches have for the cultural and social life of humans - the opportunity to adapt and improve already existing models. "Mimicry", i.e. the imitation and design-transfer from natural principles, can be combined with human creativity and serve as a tool not only for generation of new solutions, *but also for the elaboration of existing ones* that have proved to be insufficiently adaptive and resilient in the long run or with too negative an impact both on the aesthetic and socio-cultural qualities of the architectural object, as well as on the health-related factors of the changing micro- and macroclimate, that they inevitably cause.

[24] Pawlyn, Michael. "Biomimicry in Architecture", Riba Publishing, 2011, p.143

List of summarized contributions of the doctoral research:

1. A review of basic and actively elaborating terminology has been carried out - in order to clarify the emerged mutual semantic interrelation, from a contemporary point of view, and to outline its utilization in an architectural environment.

2. Formulation of new type of extended categorization of the examined bionic and biomimetic methods and approaches in architecture – laid out into 4 main levels.

3. Contemporary bionic tendencies in specific Bulgarian architectural environment are outlined and summarized

4. Comparison has been made between the higher levels of implementation of the examined bionic approaches with other contemporary architectural tendencies (ecological and sustainable), their interrelations and potential directions for reciprocity and complementarity are determined.

5. Author's criterion for symbiosis(symbioticity) in architecture is developed. It is also considered as an additional auxiliary tool for heuristic analysis and optimization pursuits in the general field of architectural theory and design.

6. Two hypothetical transformations are proposed - bionically inspired and based on architectural approaches, originating from traditional techniques - a new combination of materials and strategies, aiming increased efficiency and improved performance and sustainable characteristics of the architectural "organism".

7. The directions and levels of transformation of the examined bionic approaches and the potentials for future development and further research endeavours are outlined and summarized.

List of papers - conference participation:

- *Tsekova,* Nona. “Bionics and Biomimetics in contemporary Architecture and Design. From the sensory to technology” (Бионика и Биомиметика в съвременната архитектура и дизайн. От сетивното към технологията). Third International Conference - ISC “In search of identity”, Veliko Tarnovo, Bulgaria, 01-02.12.2016

- Tsekova, Nona. Biomimetic principles in sustainable architecture design, using natural materials as straw, clay and mycelium, International conference Arquitectonics: Mind, Land & Society, ETSAB, Barcelona, Spain, 31.05 – 02.06.2017

- *Tsekova,* Nona. “Space and Material in Architecture – interrelations from biomimetic point of view”. International Science Conference - “Art readings 2018 - Art in Europe: models and identities”, New Art Module, IAS(BAS), Sofia, Bulgaria, 28.03 – 30.03.2018

List of publications related to the dissertation:

- *Tsekova,* Nona. “Three-dimensional printing and the architectural education in Bulgaria” (Триизмерно принтиране и архитектурното образование в България). - “Arhitektura”, 2017, issue 5, 36-40.

- *Tsekova,* Nona. Biomimetic principles in sustainable architecture design, using natural materials as straw, clay and mycelium. - In: Final Papers, Arquitectonics 2017: ISBN 978-84-697-8413-6, online publication

- *Tsekova,* Nona. “Bionics and Biomimetics in contemporary Architecture and Design” (Бионика и Биомиметика в съвременната архитектура и дизайн). - “Arhitektura”, 2018, issue 2, 24-30

- *Tsekova,* Nona. “Eco, bio-, organic, …but in the context of Bulgarian Architecture” („Еко, био-, органик“...но в български архитектурен контекст). - “Arhitektura”, 2019, issue 2, 16-21

- *Tsekova,* Nona. “Bionics and Biomimetics in contemporary Architecture and Design. From the sensory to technology” (Бионика и Биомиметика в съвременната архитектура и дизайн. От сетивното към технологията). Third International Conference - ISC “In search of identity”, Veliko Tarnovo, Bulgaria, 01-02.12.2016, St. Cyril and St. Methodius University of Veliko Tarnovo, Faculty of Fine Arts, ISBN 978-619-208-141-6, (digital edition, 2018)

- *Tsekova,* Nona. “Space and Material in Architecture – interrelations from biomimetic point of view”. – In: Art readings 2018 – “Art in Europe: models and identities”, IAS, BAS, Sofia, 2019, ISBN 978-954-8594-78-3