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Enhancing Thermal performance Of Building Envelope using Biomimetic optimization algorithms

A Thesis Submitted in Partial Fulfillment
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Statement

This thesis is submitted as a partial fulfillment of Doctor of Philosophy in Architectural Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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Dedication

To my lovely wife “Eman Fayez” and my sons “Yamen and Ronza” who encouraged me in all hard times that I have been passing through without any hesitation or boring.

To my parents and brothers who have always encouraged me to explore and continue in creative ways.

Thesis Summary

Building envelope is the first defense line of the indoor environment in the inevitable confrontation with the outdoor environment. The main factors used for the definition of Building envelope are its function, characteristics, and impacts on whole buildings. The primary and main functions of the building envelope are to provide security and shelter. Building envelope helps in achieving comfort in built environment spaces such as daylight, thermal, acoustic, solar, indoor air quality, fire resistance, and moisture control. Building envelope is considered an essential pillar for achieving thermal comfort for the quality of the indoor environment of buildings. Building envelope contributes to providing a built environment with aesthetic quality as well.

Thermal performance of building envelope is acquired a great deal of global interest. Recently, algorithms are used in architecture for generating inspired shapes from nature which could affect thermal performance. The research investigates an architectural design Methodology based on a “Modeling–Simulation–Optimization” framework to control the thermal performance of the building envelope. The design of a parametric building envelope is optimized by biomimetic algorithms such as genetic algorithms to minimize the thermal performance. It explores the possibilities of enhancing the thermal performance of the building envelope by reducing the total thermal loads of a proposed unit in an office building. Results demonstrate that the total thermal loads for different case studies in different locations in the world are decreased when compared with the default state before the optimization process. Finally, possible configurations of the building envelope are presented to enhance thermal performance in real architectural design.

Keywords: Thermal Performance, Building Envelope, Biomimicry, Inspiration, Optimization, Genetic Algorithms.

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Although both **Yamen** (my son) and **Ronza** (my daughter) are so young right now, but they always provide me with endless power to continue this work.

Fortunately, I have also the privilege of having a lovely family and friends who had a fundamental role in getting me through the PhD process successfully:

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Date: / /

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1.1 Forward

Building envelope is the defense line of indoor environment in the inevitable confrontation with the outdoor environment. It has various functions which affect the whole building. Energy utilization in buildings is affected by many characteristics of building envelope; one of the most important aspects is the thermal performance. It is essential to use technological tools and applications for both predicting and enhancing the thermal performance of building envelope.

On the other hand, environmental psychology studies show that humans are aesthetically attracted to natural contents in terms of biophilia. These features are also found to have positive effects on human functioning and can reduce stress. However, opportunities for contact with these elements are reduced in architectural practice. It is argued how this biophilic evolution can have subtle but nontrivial adverse effects on human well-being. These can be countered by integrating key features of biophilic design and algorithms through biomimicry applications.

1.2 Research Fields

This research concentrates on studying of fascinating environmental changes brought by algorithms to biomimicry and biophilic design. This will be done through studying the following fields:

a. Biophilia, biophilic design, biomimicry.
b. Environmental impacts of building.
c. Thermal performance of building envelope.
d. Applying of digital design in architecture.
e. Most important algorithms used in architecture.
f. Applications of biomimetic optimization algorithms.

1.3 Research Problem Statement

Building envelope can influence on sustainability of buildings, functional, social and economic aspects. It is the fundamental shield of indoor environment as it can control the rates of energy that are needed for mechanical heating and cooling of the indoor environment. Designers take in consideration the importance of having a high level of thermal resistance and low level of thermal bridges in building envelope.

One of the most effecting factors on saving energy is the thermal performance of building components. Thermal performance of any building depends on the difference of temperature between the indoor environment in the building and the outdoor environment from surroundings. Thermal performance of building envelope is associated with the energy consumption which depends on heat transfer through building envelope components such as walls, windows, doors, etc. which forms the heat gain and loss conditions in the indoor environment so that it is considered the most important factor influencing thermal performance. Enhancing thermal performance of buildings is essential for reducing thermal loads to save energy consumption.

Inspiration from nature is an important source for architectural ideas and treatments. Biomimicry which derived from biophilia concept, is the examination of nature, its models, systems, processes, and elements to emulate or take inspiration from in order to solve human problems. It is anticipated that distinctions between the different kinds of biomimicry and their regenerative potential can be more easily made. As in nature, organisms which managed to survive in different environmental conditions formulate a large pool of inspiration for architects to learn and understand how to overcome the environmental problems which face humans in built environment with same environmental conditions.

Although the powerful capabilities of biomimicry applications, there is no obvious methodology which demonstrate how the integration between biomimicry and digital design could be achieved to control the environmental effects especially thermal performance of building's envelope design.

1.4 Research Question

The research should answer the following question:
How can architects use the integration between algorithmic design and biomimcry concept for building design in order to enhance thermal performance of building envelope?

1.5 Research Hypothesis

An architectural form design methodology that connects the two sides of the spectrum together by supplementing biomimetic applications with biophilic qualities could be achieved by using algorithms in order to enhance the thermal performance of buildings.

1.6 Research Objectives

Research objectives could be explained in the following points:

1.6.1 Main Objective

- Create an architectural design Methodology based on biophilic concept, biomimicry applications, thermal simulation and heuristic algorithms as a computational tool through a parametric design of building envelope to enhance thermal performance of building envelope by reducing the total thermal loads of a proposed unit of a proposed office building. The design of building envelope is optimized by biomimetic algorithms such as genetic algorithms.

1.6.2 Secondary Objectives

- Identify the relationship between algorithms, biomimicry, and biophilia.
- Investigate algorithmic design strategies.
- Analyze the applications of biomimetic optimization algorithms in architecture.

1.7 Methodology

The methodologies of the research will be as the following:

A. A literature review and data collection for the historical review of the applications of biophilia, biomimicry and algorithms in architecture.
B. An analytical study to provide an architectural design Methodology for enhancing thermal impact which caused by using biomimetic optimization algorithms.
C. A deductive analytical study for creating an architectural design Methodology based on algorithms.

1.8 Research Limitations

This research represents a study for three major ingredients which are environmental changes, digital design and biophilia effect. As this research contains a large number of factors which could affect the research results in each stage. In order to keep the research within a manageable state the research will be concentrated in a specific factor from the three major ingredients which are mentioned before. For the environmental changes, research will focus in thermal performance for building envelope which results from changing its design variables. For digital design, research will focus in algorithms used for optimization particularly biomimetic optimization algorithms such as genetic algorithms. For biophilia effect, research will focus in biophilic design patterns particularly biomimicry applications. The optimization process will be performed and managed by using a digital platform consists of many digital applications such as Rhinoceros, Grasshopper, Honeybee, Energyplus, and Ladybug.

1.9 Literature Review

Nowadays, energy conservation approach attracts more attention and encourages humans to use different strategies to achieve it in the world. According to Brown et al. (2017)[1], energy levels increase as a result of pollution and global warming. The total consumption of energy in

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[1] Brown, K. E., Henze, D. K., & Milford, J. B. (2017). How accounting for climate and health impacts of emissions could change the US energy system. Energy Policy, 102, P:396-405.

the world has three major causes which are industries, buildings and transportation. Energy consumption of buildings is one of the most important pillars for energy conservation[1]. In studies carried out by U.S. Energy Information Administration (EIA, 2016)[2] states that buildings consume more than 20% of total energy in the world.

Thanks to information technology, the old ways of energy performance calculations were developed. As Augenbroe (2002)[3] explained that the new process used to calculate energy performance of buildings is called energy simulation or energy building modeling. By the different stages of energy simulation process during the design process, architects could predict and analyze the resulted consumption of energy in any part of the building and this could be used to change the energy consumption as needed in this specific location in the building. This advantage of energy simulation supply architects by many proposed ideas to use in order to achieve the maximum use of energy without raising consumption rates.

Since few decades, the rates of energy consumption by building usage in the world have increased rapidly. According to studies in the future rates of energy consumption in the world, EIA stated that the rate of energy consumption will be 1.5% per a year during the period from 2012 to 2040[4].

The using of optimization in design launched since 1980. However, as Nguyen et al. (2014)[5] stated the most of directions of research and studies about using mathematical optimization and energy performance simulation and biomimetic optimization algorithms for building design were published since 2000. Designers in the optimization process seek to find the optimal solutions by using parametric design and energy metrics of the design variables and conditions which fulfill its needs and functions. In the past it is not possible to perform such incredible simulation processes with optimization attitude.

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[1] EIA. (2016). ENERGY STAR® portfolio manager™: U.S. energy use intensity by property type. Washington, DC: EPA.
[2] EIA. (2016). Ibid.
[3] Augenbroe, G. (2002). Trends in building simulation. Building and Environment, 37(8), P: 891-902.
[4] EIA. (2016). Ibid.
[5] Nguyen, A., Reiter, S., & Rigo, P. (2014). A review on simulation-based optimization methods applied to building performance analysis. Applied Energy, 113, P:1043-1058.

Among the recent researches about building performance optimization Evins (2013)[1] found that genetic algorithms is the most optimization strategy used in optimization process as it was used nearly in 50% of all researches while the other strategies used in the rest studies are particle swarm, simulated annealing and direct search. The most optimization purpose in the studies reviewed by Evins (2013)[2] was energy consumption with 60% share of all researches and studies, while the other 40% percentage is divided into other purposes such as day lighting systems, cost, CO2 emissions, etc.

Xinga, Yu, Zhang, and Wu (2018) [3] investigated a new energy-efficient building system for enhancing the thermal performance of public buildings to maximize energy-saving up to 65% in cold climates. The proposed system was based on using a modified insulated concrete perforated brick with a sandwich. The new modified brick was re-examined many times to reach the optimum value of insulating layer thickness which achieves the best values for energy saving. The results show that by using the new type of bricks in walls, the heat transfer coefficient could be minimized by 45% comparing to walls are made by unmodified bricks with the same thickness. The optimum value for insulating layer thickness in improved bricks was 65 mm as by using it in walls heat transfer coefficient achieves a minimum value of 0.45 and could reach the energy-saving requirement of 65% for buildings in cold climates.

According to a study implemented by Evins (2013)[4] in the field of optimization of building performance, building envelope has the higher percentage of research papers as it approximately reaches 38% of the reviewed work while the percentage of building form researches is 21%, the generation of renewable energy researches percentage is 16%, the percentage of HVAC system is 17% and the rest of the reviewed research focuses on lighting strategies.

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[1] Evins, R. (2013). A review of computational optimisation methods applied to sustainable building design. Renewable and Sustainable Energy Reviews, 22, P:230-245.
[2] Evins, R. (2013). Ibid, P:230-245.
[3] G. Xinga, J. Yu, C. Zhang, J. Wu (2018), A new energy-efficient building system based on insulated concrete perforated brick with a sandwich, Civil Engineering Journal Vol. 4, No. 7, P:1467-1476.

[4] Evins, R. (2013). Ibid, P:230-245.

In 2017, Fan and Xia[1] performed an optimization process based on genetic algorithms to retrofit building envelope. Fan and Xia managed to design a retrofitting plan that could last for 24 years. The optimization processes aims to achieve an optimal solution with both minimum energy consumption and larger economic rates. The study concentrated in using design variables such as wall types, window types, door types, materials and solar panels types on the rooftop.

Jalil, Naji, and Mahmood (2020) [2] studied the environmental benefits of using the waste caused by destroyed buildings in the reconstruction process. The main concern of this study was building sustainability in terms of the consumption of energy. The authors proposed three alternatives of building materials to use in buildings which were: 10% recycled fine aggregates, 100% recycled fine aggregates, and crushed clay brick aggregate (CCBA) to produce recycled coarse aggregates for examining and determining the best alternative in terms of energy consumption. The study based on using building information modeling (BIM) technology to examine the energy consumption life cycle and annual carbon emissions of the proposed alternatives and compare the results with the actual values of the same building in the case of reconstruction using natural building materials. The study concluded that the best alternative was the use of crushed clay brick aggregate (CCBA) as it can minimize the energy consumption five times lower than the same building with natural materials, while the results of carbon emissions were equal as for the electricity consumption decreased from 23,500 kW/h to less than 23,000 kW/h.

According to Wang & Zhai (2016)[3], the used tools in recent researches and studies for calculating energy performance of any part of the buildings are more easy and accurate as well. The new tools for energy simulation enables architects to save time, transfer data easily, view results simultaneously and select the optimal solution. There are many energy simulation tools such as Energy10, TRACE 700, IES-VE, Energy-Plus, DOE-2, and HAP. Mateus, Pinto, & da Graca, 2014 used Enrgy-Plus simulation tool in their studies about thermal

[1] Fan, Y., & Xia, X. (2017). A multi-objective optimization model for energy-efficiency building envelope retrofitting plan with rooftop PV system installation and maintenance. Applied Energy, 189, P:327-335.
[2] Z. A. Jalil , H. I. Naji , M. S. Mahmood (2020), Developing sustainable alternatives from destroyed buildings waste for reconstruction projects, Civil Engineering Journal Vol. 6, No. 1, P:60-68.
[3] Wang, H., & Zhai, Z. J. (2016). Advances in building simulation and computational techniques: A review between 1987 and 2014. Energy and Buildings, 128, P:319-335.

simulation of double skin façade ventilation and it reflects high levels of accuracy and validation.

Borgstein et al. (2016)[1] explained that the calculation of energy performance of buildings is necessary to evaluate the energy consumption in building during any period in the year according to its climate conditions of its location. The energy performance of any building could be affected by many indoor and outdoor factors such as occupants' needs and activities, internal and external finishes, building envelope, weather condition of building location and plug loads.

Schwartz et al. (2016)[2] performed an optimization process using genetic algorithms for the refurbishment of a residential building. For the optimization process, the aim is to have the minimum life cycle cost and life cycle carbon footprint over 60 years. While the design variables which the optimization process depended on window to wall ratio, thermal bridge insulation and wall insulation material f the residential complex. The optimization process achieves the aims and identifies the optimal solution with valuable results as well. One of the most important results of the optimization process is the prediction of long life cycle carbon emissions during annual energy consumption optimization.

In a study by Cao et al. (2016)[3], they considered that the causes which led to increase energy consumption rates are changing in climate around the globe, the new attitude of people to stay in homes, the great indoor environment quality which attract human to stay in buildings along the day and night, the increased rates of population around the world as the number of consumers increased as well and the existing of multi-function building which consume more energy to perform multi tasks and functions in its spaces.
In 2016, Zhang et al. (2016)[4] developed a new approach for optimizing the shape of free form building according to efficiency of

[1] Borgstein, E., Lamberts, R., & Hensen, J. (2016). Evaluating energy performance in nondomestic buildings: A review. Energy and Buildings, 128, P:734-755.
[2] Schwartz, Y., Raslan, R., & Mumovic, D. (2016). Implementing multi objective genetic algorithm for life cycle carbon footprint and life cycle cost minimisation: A building refurbishment case study. Energy, 97, P:58-68.
[3] Cao, X., Dai, X., & Liu, J. (2016). Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade. Energy and Buildings, 128, P:198-213.
[4] Zhang, L., Zhang, L., & Wang, Y. (2016). Shape optimization of free-form buildings based on solar radiation gain and space efficiency using a multi-objective genetic algorithm in the severe cold zones of china. Solar Energy, 132, P:38-50.

indoor environment and outdoor solar radiation. The parametric model of the free form building was built by using both Rhinoceros and Grasshopper applications' platform. The optimization process objectives were maximum space efficiency, minimum solar radiation gain and minimum shape coefficient of the building. The results of the study were tested with the comparison between a pure cube shaped of a building which was tested under the same circumstances and objectives. The final results showed that the pure cube shaped building is 47%:70% lower than free form building for solar radiation, 80%:85% higher than free form building for shape coefficient, and 95% higher than free form building for space efficiency.

In 2016, a research by Mahmoud and Elghazi[1] investigated the best performance of daylight of the optimal design proposal for a kinetic envelope design by using an experimental methodology depending on optimization process.

The research carried out by Anđelković et al. (2016)[2] is an example of using Energy-Plus as a simulation tool to study the Application of a multi-storey naturally ventilated double skin façade which used experimental validation of Energy-Plus tool. All these tools and applications concentrate of building energy modeling and calculate thermal comfort, thermal performance, energy consumption, energy efficiency, acoustics, lighting performance, and ventilation in indoor environment.

Azari et al. (2016)[3] adopted an optimization process depending on genetic algorithms for optimizing the life cycle impacts on environment and energy consumption. In this study the optimization process depends on many design variables such as window type, window material, window to wall ratio, insulation material properties, and thermal resistance of building envelope. Genetic algorithm was used in this process as an effective optimization process with the help of eQuest 3.65 application as a thermal simulation engine.

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[1] Mahmoud, A. H. A., & Elghazi, Y. (2016). Parametric-based designs for kinetic facades to optimize daylight performance: Comparing rotation and translation kinetic motion for hexagonal facade patterns. Solar Energy, 126, P:111-127.
[2] Anđelković, A. S., Mujan, I., & Dakić, S. (2016). Experimental validation of a EnergyPlus model: Application of a multi-storey naturally ventilated double skin façade. Energy and Buildings, 118, P:27-36.
[3] Azari, R., Garshasbi, S., Amini, P., Rashed-Ali, H., & Mohammadi, Y. (2016). Multiobjective optimization of building envelope design for life cycle environmental performance. Energy and Buildings, 126, P:524-534.

In 2015, Carlucci et al.[1] proposed an optimization process for a residential house in Italy. The optimization process aims to have a net zero-energy house by minimizing the visual and thermal discomfort. The study depends on four optimization variables which were firstly, minimizing the visual discomfort which arises from either not suitable day lighting rates or glare and secondly, minimizing the thermal discomfort during the period of summer and winter. The optimization variables for this study are window type, window to wall ratio, wall type, shading devices strategies, glazing material properties, roof material properties, and floor material properties. The thermal and day lighting simulation engine in this study is Energy-Plus while GenOpt was used as an optimization tool.

In hot and humid climate, a new optimization process was investigated by Ercan et al. (2015)[2] to identify the optimal dimension and properties of an office building shading device. The main objective of the optimization process is to achieve the maximum level of daylight in the office building by reaching the optimal design of the shading devices of the building envelope. In order to perform the whole process, Ercan et al. (2015)[3] built a parametric model for the office building envelope in Rhinoceros and Grasshopper applications. Grasshopper application helped in generating many design proposals for the design of shading devices.

Caruso and Kämpf (2015)[4] developed an optimization process for the building form to achieve the minimum rates of energy consumption which arises from solar irradiation. The optimization process depends on calculating the total solar irradiance which fall in the building envelope and tend to change the shape and the form of the building to have the minimum values. An evolutionary algorithm was used as an optimization tool to identify the best solution. The results of the study show the best solution through examining a large number of building form according to the optimization variables and desired purposes.

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[1] Carlucci, S., Cattarin, G., Causone, F., & Pagliano, L. (2015). Multi-objective optimization of a nearly zero-energy building based on thermal and visual discomfort minimization using a non-dominated sorting genetic algorithm (NSGA-II). Energy and Buildings, 104, P:378-394.

[2] Ercan, B., & Elias, O. (2015). Performance-based parametric design explorations: A method for generating appropriate building components. *Design Studies, 38,* P:33-53.

[3] Ercan, B., & Elias, O. (2015). Ibid, P:33-53.

[4] Caruso, G., & Kämpf, J. H. (2015). Building shape optimisation to reduce air-conditioning needs using constrained evolutionary algorithms. *Solar Energy, 118,* 186-196.

According to a study carried by Ascione et al. (2015)[1] for a residential building, an optimization process performed to optimize both thermal comfort and energy consumption. The optimization parameters were connected to building envelope thermal performance such as thermal capacity, thermal transmittance, radiated properties of building envelope materials. The optimization process was applied to a residential building in two different locations within Mediterranean climates. The study managed to identify different optimal solutions for different location of the residential buildings. In this study Energy-Plus was used as a thermal simulation engine while genetic algorithms was used as an optimization methodology.

By using parametric design, Lin and Gerber (2014)[2] investigated an Evolutionary energy performance feedback for design (EEPFD) as a design methodology for green buildings. Lin and Gerber (2014)[3] developed a prototype tool H.D.S. which is a new application helps in the methodology process. The new H.D.S. tool could plug in the powerful application Autodesk Revit to perform the simulation for the parametric model. Thanks to H.D.S. tool it was possible to combine the features and properties of Autodesk Green Building Studio and Microsoft Excel to facilitate the optimization process. The research purpose was to find the building form which achieves maximum financial rates, energy conservation and the spatial programing elasticity.

A new methodology for optimizing building envelope was proposed by Lartigue et al. (2013)[4]. The proposed methodology depends on maximizing the daylight while in other hand minimizing cool and heat loads in the space. The optimization variables were assigned to both window type and window to wall ratio of the space. The study depends on many applications to perform the optimization process such as Daysim application for day lighting simulation, TRNSYS for energy performance simulation, and GenOpt as an optimization tool.

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[1] Ascione, F., Bianco, N., De Masi, R. F., Mauro, G. M., & Vanoli, G. P. (2015). Design of the building envelope: A novel multi-objective approach for the optimization of energy performance and thermal comfort. Sustainability, 7(8), 10809-10836.

[2] Lin, S. E., & Gerber, D. J. (2014). Designing-in performance: A framework for evolutionary energy performance feedback in early stage design. Automation in Construction, 38, 59-73.

[3] Lin, S. E., & Gerber, D. J. (2014). Ibid, 59-73.

[4] Lartigue, B., Lasternas, B., & Loftness, V. (2013). Multi-objective optimization of building envelope for energy consumption and daylight. Indoor and Built Environment, 1420326X13480224.

For identifying the minimum consumption of energy while providing the space of a room as a case study by suitable indoor temperature, Kusiak and Xu (2012)[1] tested the HVAC system during the optimization process to achieve the optimal solution for the desired state. Kusiak and Xu (2012)[2] managed to minimize the energy consumption by 29.9%. In this optimization process, there are twenty one variables which were tested as a candidate for the optimization process to find the optimal solution. These variables contain the temperature of supply air, actual room temperature, actual room humidity and fan speed of HVAC system. The optimization strategy used in this process was based on particle swarm optimization algorithm.

In order to optimizing the building envelope components and building form, Tuhus and Krarti (2010)[3] proposed a design methodology for the optimization process. The process depends on genetic algorithms as a simulation engine. The main purpose of this optimization process is to identify the optimal solution which achieves the minimum levels of energy consumption in the building. Tuhus and Krarti (2010)[4] examined different shapes of building such as T, L, U, H, trapezoid, square, cross, and rectangle shapes in the design process. Optimization variables which the study depends on for building envelope design were window types and sizes, wall types, roof material, insulation type, and foundation types. The results of this study indicates that trapezoid and rectangular shapes are the best solution for building shape to have minimum levels of energy consumption and have the minimum life cycle cost as well.

Kayo and Ooka (2009)[5] investigated an optimization process depends on genetic algorithm for optimizing the energy system in of a hospital building in Tokyo. They aim to achieve an optimal design of the hospital building which has the minimum value of both cost and

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[1] Kusiak, A., & Xu, G. (2012). Modeling and optimization of HVAC systems using a dynamic neural network. Energy, 42(1), P:241-250.
[2] Kusiak, A., & Xu, G. (2012). Ibid, P:241-250.
[3] Tuhus-Dubrow, D., & Krarti, M. (2010). Genetic-algorithm based approach to optimize building envelope design for residential buildings. Building and Environment, 45(7), P:1574 1581.
[4] Tuhus-Dubrow, D., & Krarti, M. (2010). Ibid, P:1574-1581.
[5] Kayo, G., & Ooka, R. (2009). Application multi-objective genetic algorithm for optimal design method of distributed energy system. Paper presented at the Eleventh International IBPSA Conference, P:27-30.

energy consumption. This study focused on specific design parameters such as hot heat supply, cool heat supply, electricity usage and hot water supply.

By performance evaluation for four types of shading devices, Chiang et al. (2008)[1] managed to study the different dimensions of a classroom such as height, length and width and reach to the maximum artificial lighting distribution in the classroom.

In a study carried out by Wright et al. (2002)[2], the optimum feasibility solution related to the relation between thermal discomfort of space occupants and energy cost was identified by using an optimization method depends on genetic algorithms. There are many variables in the optimization process such as HVAC system, air flow rate, air temperature and number of circuits.

1.10 Research Structure

This research consists of six chapters as following:

Chapter one presents research scope and literature review of most recent studies in the field of research as energy conservation approach attracts more attention and encourages researchers to use different strategies to achieve it. The total consumption of energy in the world has three major causes which are industries, buildings and transportation. Thanks to information technology, the old ways of energy performance calculations were developed. The new process used to calculate energy performance of buildings is called energy simulation or energy building modeling. By the different stages of energy simulation process during the design process, architects could predict and analyze the resulted consumption of energy in any part of the building and this could be used to change the energy consumption as needed in this specific location in the building. This advantage of energy simulation supply architects by many proposed ideas to use in order to achieve the maximum use of energy without raising consumption rates.

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[1] Chiang, C., Ho, M.,Chou, P., Chang, K., & Lee, C. (2008). Optimal sun-shading design forenhanced daylight illumination of subtropical classrooms. Energy and Buildings, 40(10), P:1844-1855.
[2] Wright, J. A., Loosemore, H. A., & Farmani, R. (2002). Optimization of building thermal design and control by multi-criterion genetic algorithm. *Energy and Buildings, 34*(9), 959-972.

Chapter two presents a theoretical study for thermal performance of building envelope. Thermal performance is the formulation of energy transfer between both indoor and outdoor environments. It has a great impact on energy consumption in buildings as it can manipulate on different and essential aspects of buildings. Each building has a state of thermal balance depending on five pillars that formulate the comfortable state of balance. The five pillars could be categorized as envelope thermal transfer value, heat transfer rate via ventilation, building's solar heat gain, building's internal heat gain and evaporation heat loss. Organisms in nature managed to formulate their abilities in order to reach the thermal balance state which is essential to survive in harsh environmental conditions. The studying and understanding for heat regulation in nature occurs by organism strategies led to find innovative solutions for building to control thermal performance for achieving thermal comfort rates. The inspiration of nature strategies depends on the main idea of biophilia effect between human and nature.

Chapter three presents a theoretical study for biomimicry in architecture. Biomimicry is the process of imitating natural organism strategy in order to benefit similar problem which it managed to solve it in natural life. Biomimicry is considered the most important and essential fertile source of inspiration for new innovative solutions for designers to overcome, control and enhance different environmental conditions. Biomimicry has two approaches to be used through their processes which are design looking to biology and biology influencing design. The application of biomimcry could be inspired from forms of natural organisms' composition, forms of structures in nature and materials owned by natural organisms. Each application of biomimicry is led by a biomimicry level which helps in formulating the whole process of biomimcry. Levels of biomimicry are categorized to three main levels organism level, behaviuor level and ecosystem level. It is needed for performing a successful process of biomimcry for enhancing thermal performance of building envelope to choose the suitable biomimicry approach, application and level. Depending on biomimicry inspiration, a digital model for building envelope design could help in controlling and examining the thermal performance of building envelope which is inspired from nature.

Chapter four presents an analytical study for biomimetic optimization algorithms. In digital information age, algorithms were used in digital design due to its ability for generating, controlling and changing the final product easily. An infinite number of generations could be produced by a single and simple algorithm formation which supplies designers with enormous number of complicated concepts and ideas. Designers by themselves and their own abilities cannot imagine and predict the results of performing algorithm according to the complicated mathematical equations and process so algorithms open a massive source for new and innovative concepts and ideas for designers. Algorithms is used not only to produce a digital model to any desired concept but also it is used to choose and identify the optimum solution for the input data and conditions which designers select to solve. Concepts and ideas which laterally are modeled by using algorithms could be inspired from nature by using biomimicry. The correlation between using algorithms for optimization and biomimicry for inspiration called biomimetic optimization algorithms. There are various number of successful biomimetic optimization algorithms. Biomimetic (nature-inspired) optimization algorithms could be divided to two main categories. The first main group is biologically inspired algorithms which depend on the inspiration of organism and this category is divided to evolutionary based algorithms, swarm based algorithms and ecology based algorithms. The second main category is Physics/Chemistry- based algorithms which are not biologically inspired algorithms but still nature-inspired algorithms.

Chapter five presents an analytical study for the optimization process of a new design methodology to enhance thermal performance of digital design of building envelope. The proposed optimization framework provides optimization concept, methodology, two types of design variables, limitations of optimization process, Rhinoceros and Grasshopper applications as parametric platforms for digital modeling of building envelope, and EnergyPlus as a simulation engine for the optimization process. The seven steps of optimization process for building envelope are discussed in detail to explain how building envelope is modeled, tested, and optimized to minimize thermal performance. Through the research methodology, the results of optimization process by using the proposed design of building envelope lattice for the proposed design of office unit and assigned weather conditions the total thermal loads are less than the total thermal loads of the default state before optimization process. According to the previous results, the proposed lattice design with assigned values for rotation angle and enclosure angle by using biomimetic optimization algorithms such as genetic algorithms enhances thermal performance of building envelope.

Chapter six presents the conclusions and recommendations of research. The research based on presenting a design methodology to enhance thermal performance of building envelope. The proposed design methodology emerged from the integration between many ingredients which were: digital design of building envelope, environmental effect of building envelope on building sustainability, thermal regulation in buildings, biomimicry concept, biomimetic optimization algorithms and energy simulation in building sample. The literature review which presents the capabilities of building envelope, biomimicry, energy simulation, digital design and biomimetic optimization algorithms for enhancing thermal performance in many ways indicates that the combination between them all effects on both building envelope design and thermal performance. According to the proposed optimization process, input data for six selected cities located in different locations in the world which assigned as research case studies, research variables and limitations of the new design methodology of building envelope provides a thermal performance reduction for building envelope lower than the thermal performance for the same case study's building envelope without any treatments which affect thermal performance. So the integration between biomimicry, digital design, and optimization algorithms is an effective way to evaluate and find optimal solution for building envelope design to enhance thermal performance of it. As a conclusion from research results, the proposed design methodology for building envelope to enhance thermal performance by using biomimetic optimization algorithms managed to provide significant optimal solutions for building envelope design with thermal performance improvements. So it can be considered as a valid methodology for enhancing thermal performance of building envelope.

For further research directions, it could include different types of biomimetic optimization algorithms to develop new types with new inspiration concepts to generate innovative solutions for environmental problems. The proposed design methodology offers a large number of chances and opportunities which attracts future researchers to use its capabilities in improving and enhancing many factors in built environment such as enhancing daylight qualities, Acoustics in buildings, shading devices, life cycle cost.

Research structure is presented in the following figure:

Chapter one	Research Scope
Chapter Two	Thermal Performance of Building Envelope
Chapter Three	Biomimicry In Architecture
Chapter Four	Biomimetic Optimization Algorithms
Chapter Five	Optimization Process
Chapter Six	Conclusions And Recommendations

Chapter Two
Thermal Performance of Building Envelope

Chapter Two
Contents

Thermal Performance Of Building Envelope

Chapter Two
Thermal Performance of Building Envelope

2.1 Introduction

In this chapter, the research concentrates on building envelope's characteristics and functions. Building envelope has many effects on building and built environment as well. These effects include environmental, functional social, and economic. The research focuses on environmental effects especially thermal performance of building envelope. Thermal performance generally has different mechanisms to transfer heat through building envelope components which affect thermal balance of buildings.

2.2 Definition of Building Envelope

Building envelope definition as Brock (2005) stated [1], "It is the skin of a building which is supported by the skeleton of the building structure", while Elder (2005) explained it as "the building components which enclose conditioned spaces and through which thermal energy is transferred to or from the outdoor environment" [2]. The building components include all determinants of architectural space such as walls, roofs, floor, doors and windows.

2.3 Fundamental Functions of Building Envelope

The fundamental function of building envelope is to provide shelter and security which contains in its domain the fulfillment of comfort rates of thermal, solar, acoustic, fire resistance, indoor air quality and moisture control [3]. Leung et al. (2005) stated that building envelope has to provide other functions such as the psychological needs of the building occupants thought out allowing the connected view between inside and outside the building in order to provide both sufficient natural lighting rates to building occupants and preventing the feeling

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[1] Brock, L. (2005), "Designing the exterior wall: an architectural guide to the vertical envelope".
[2] Elder, K. E. (2005), "Building Envelope".
[3] Brock, L. (2005), "Designing the exterior wall : an architectural guide to the vertical envelope".

of isolation by occupants. One of the building envelope functions is the aesthetic quality of the building in the outdoor environment as any building should has an attractive image to project it in the built environment. Both cost and impacts on local environment are considered effective pillars of building envelope functions [1].

2.4 Effects of Building Envelope on Sustainability of Buildings

Building envelope effect on sustainability of buildings as it can affect environmental, functional, social and economic aspects of any building [2][3]. The following explanation describes each aspect in details:

2.4.1 Environmental Effect of Building Envelope

The sustainable building requests to reduce retro-gradation of environment and consumption of resources. In passive systems of sustainable buildings, building envelope is considered the most important parameter and largest size element which could affect both retro-gradation of environment and consumption of resources [4].

Building envelope is the connection between the outdoor environment and the indoor environment. It is the fundamental shield of indoor environment as it can control the rates of energy that are needed for mechanical heating and cooling of the indoor environment [5]. Throughout controlling the thermal potential of building envelope, the rates and levels of mechanical energy usage could be minimized. Building envelope could control the amount of heat gain which rolls in the indoor environment and heat loss in the outdoor environment[6].

[1] Leung, T. M., Chau, C. K., Lee, W. L., & Yik, F. W. H. (2005), “Willingness to pay for improved environmental performance of the building envelope of office buildings in Hong Kong”. P:147-156.
[2] Kibert, C. J. (2005), “Sustainable construction : green building design and delivery”
[3] Lucuik, M., Trusty, W., Larsson, N., & Charette, R. (2005), “A Business Case for Green Buildings in Canada”.
[4] Manioglu, G., & Yilmaz, Z. (2006), “Economic evaluation of the building envelope and operation period of heating system in terms of thermal comfort”. P.266-272.
[5] Manioglu, G., & Yilmaz, Z. (2006). Ibid.
[6] Elder, K. E. (2005), “Building Envelope”.

Examples of how building envelope could control heat gain and loss by its characteristics are discussed as follows:

- Elder (2005) stated that, the components of building envelope such as framing system could affect heat loss as when using metal stud framing system for walls, heat loss is doubled [1].

- Isolation of building envelope could minimize or maximize the cooling energy needed for indoor environment. Cheung et al. (2005) explained that by installing 100mm thick heat insulation on walls, the annual cooling energy needed could be minimized up to 19.4 % in a hot-humid climate. Generally in hot-humid climate, the more the thickness of insolation is used, the less the rates of cooling energy are required [2].

- Cheng et al 2005 stated that the color of building envelope could affect solar heat gain from the surrounding environment [3]. According to Cheung et al. (2005), the more bright the buildings envelope has, the lower the solar radiation is absorbed. If solar absorption is reduced by 30%, the annual energy needed for cooling will be reduced by 12.6% [4].

- Building envelope thermo-physical characteristics could affect indoor environment temperature by thermal regulation rules. As per the studies carried out by Wong (2003) and Cheung et al. (2005), Building envelope with light colors has the ability to reflect light better than the ones of dark colors and contributes to lower surface temperature of the façade. These characteristics of light color building envelop led to have comfortable temperature levels of indoor environment [5]. Another study examined by Oral and Yilmaz (2003) showed that the U-value of building envelope could affect the indoor

[1] Ibid.
[2] Cheung, C. K., Fuller, R. J., & Luther, M. B. (2005), “Energy-efficient envelope design for high-rise apartments”. P: 37.
[3] Ibid. P: 40.
[4] Ibid. P: 42.
[5]Cheung, C. K., Fuller, R. J., & Luther, M. B. (2005), “Energy-efficient envelope design for high-rise apartments”. P: 41.

thermal properties as it is considered to influence the heat transfer rate through the whole building [1].

- Stansfield (2001) explained that glazing system is considered one of the most important components of building envelope as it is the barrier in which most heat gain and loss occur. The energy efficiency of the whole building depends on the energy efficiency of glazing system of building envelope. When improving energy efficiency of glazing system, the energy efficiency of the building is increased. In field study performed by Stansfield (2001), the glazing system of proposed building envelope was replaced by a single layer Evergreen™ with a reflective coating which led to decrease the annual cooling energy by 4.6% and peak cooling load by 5.4% [2].

- According to Cheung et al. (2005), shading devices used in building envelope could affect heat gain and energy consumption of buildings. Cheung et al. (2005) stated that the longer the shading device, the greater the decrease of both needed annual cooling energy and peak cooling load. Based on the study carried out by Cheung et al. (2005), if building envelope has a shading device of 500 mm over hang long, the building will save approximately 100kw/year [3].

- In 1986, Rush & American Institute of Architects any building has to provide six performance delegations which are spatial Performance, thermal performance, acoustical performance, building integrity performance, indoor air quality performance and visual performance [4].

2.4.2 Functional Effect of Building Envelope

Buildings mainly are built to fulfill the needs of its users so function of occupants which will be performed in building spaces is very important aspect. Building envelope works as a filter which provide

[1] Oral, G. K., & Yilmaz, Z. (2003), “Building Form for cold climate zones related to building envelope fromheating energy conservation point of view”. P: 383-388.
[2] Stansfield, K. (2001), “Whole-life performance of facades”. P: 15-17.
[3] Cheung, C. K., Fuller, R. J., & Luther, M. B. (2005), “Energy-efficient envelope design for high-rise apartments”. P: 43.
[4] Rush, R. D., & American Institute of Architects. (1986), “The Building systems integration handbook”.

safe and secure for occupants and protect indoor environment from any harmful and non-preferable issues comes from outdoor surroundings [1]. Building envelope can help other building systems in order to handle and manage the overall building performance. Elder stated that, "without a good understanding of how the envelope performs, a complete understanding of the interactive relationships of lighting and mechanical systems cannot be obtained" [2]. So overall building performance depends on how building envelope is designed to integrate and interact with other building systems such as mechanical systems, interior systems, structural systems, etc [3].

2.4.3 Social Effect of Building Envelope

One of the most important factors of sustainable building is achieving healthy and comfortable indoor environment. The definition of comfort proposed by Unver et al. (2003) defines it as it is the way which allows occupants to perform their functions and needs in indoor environment easily for long period of time [4]. Building envelope is an important factor to provide this condition of social comfort because it is considered as barrier which can protect indoor from the harmful exposure to outdoor[5].

2.4.4 Economic Effect of Building Envelope

As stated in the Centre for Window and Cladding Technology (1994), the building envelope is the single largest cost in the construction of many buildings so the role of building envelope on the building's overall initial costs is significant. The maintenance of building envelope components has a great effect on financial cost in the life cycle of building cost as it uses large amounts of materials. Therefore, the use of energy of extraction, manufacturing, transporting, installing and disposing needed for each of the building envelope components

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[1] Mary, G. (2010), "Towards Zero Energy Architecture–New Solar Design". p 124-127.
[2]Elder, K. E. (2005), "Building Envelope".
[3] Kunzel, H. M., Holm, A., Zirkelbach, D., & Karagiozis, A. N. (2005), :Simulation of Indoor Temperature and Humidity Conditions Including Hygrothermal Interactions with the Building Envelope". P: 554-561.
[4] Unver, R., Ozturk, L., Adiguzel, S., & Celik, O. (2003), "Effect of The Facade Alternatives on The Daylight Illuminance in Offices". P: 737-746.
[5] Wong, N. H. (2003), "Thermal Performance of Façade Materials and Design and the Impact on Indoor and Outdoor Environment".

are beginning to be included in the life cycle cost analysis as an environmental cost.

On another point of view, building envelope could affect the investment returns directly because the building envelope reflects the visual image and aesthetic quality to indicate level of welfare of the building which is useful in marketing the whole building. Owners and developers tend to construct building with high marketing value in order to compete in the real estate market [1].

2.5 The Role of Building Envelope in Achieving Thermal Comfort

The American Society of Heating Refrigerating and Air-Conditioning Engineers “ASHRAE-55” (2004) define thermal comfort as the state of mind in humans that expresses satisfaction with the surrounding environment [2]. This definition agrees with the proposed one by World Health Organization “WHO” (2012) [3] which stated that the satisfaction with room humidity, indoor air circulation, temperature and an adequate balance between the perception of warm and cold, as well as dry and damp indoor air. Thermal discomfort arises from any condition contrary to this balance condition.

The dominant key for the quality of indoor environment is thermal comfort whereas thermal comfort is an index which indicates to good indoor quality. According to the study performed by Appah and Korantengin (2012), in architectural spaces, humans need to preserve the individual internal body temperature of around 37ºC which humans can perform their activities in sufficient levels [4].

Generally, comfort perception differs between humans as it is a subjective state depends on the personality and feelings of each

[1] Schwartz, J., & Kayll, D. G. (2005), “Building Envelope Performance: What to Expect when You are Expecting”.
[2] ASHRAE-55 (2004), “Thermal Environmental Conditions for Human Occupancy. A Fundamental Handbook of the American Society of Heating”.
[3] WHO (2012) A World Health Organisation Newsletter (2012), symposium on ‘Housing and Health’.
[4] Appah-Dankyi, J. and Koranteng, C. (2012), “An Assessment of Thermal Comfort in a Warm and Humid School Building at Accra, Ghana”. P: 535-547.

occupant of the architectural space [1],[2],[3]. It is the sum of many components consists of firstly environmental variables found in the building such as mean radiant temperature, relative humidity, air velocity and indoor air temperature and secondly physiological variables Such as Clothing Insulation and Metabolic Heat Production Rate. There are more variables could affect comfort perception for humans which is separately categorized into time of year, location, culture, health status and percentage of fat in an individual [4].
Finding a common comfort range is an attractive subject which has a great concern for researches for a long time. As per Ward (2004) Explanation of thermal comfort, humans feel the surrounding environment is thermally comfort when thermal neutrality presents or in other words there is no thermal discomfort exists [5]. The thermal discomfort state occurs when humans feel cold or hot because of there is no thermal neutrality in indoor environment. Human's perception of thermal comfort is particularly influenced by building envelope components and properties.

Studies investigated by Torben and Peter (2010) concluded that the climatic state under which humans are most comfortable and can perform their activities well is around temperature degrees of 22ºC±2ºC for either while resting or work conditions [6]. However, for buildings in tropic climates it could be have a wider range when considering adaptive comfort approach as according to researches performed by Kayode and Folorunso (2004) for studying frequency distribution of air temperatures and comfort votes in Lagos, Nigeria, the ranges of the comfortably cool temperatures lies between 24ºC and 26ºC, while the comfortably warm temperatures lies between 28ºC and 30ºC [7].

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[1] Bill, W. and Randall, T. (2000), “Comfort Health and Environmental Physics In: Randall”.
[2] Thomas, Max Fordhain & Partners (eds) (2013), “Environmental Design: An Introduction for Architect and Engineers”. P: 7-14.
[3] Phil, J. (2012), “Thermal Environment In: David Littlefield (ed) Metric Handbook Planning and Design Data”. P: 15-18.
[4] Thi, T.T.C. (2011), “Investigating Thermal Properties of Facades for Thermal Comfort and Energy Efficiency of High Rise Residential Buildings in Singapore”.
[5] Ward, I.C. (2004), “Energy and environmental issues for the practising architect: a guide to help at the initial design stage”. P: 30.
[6] Torben, D. and Peter, S. (2010), “Introductory Note In: Torben Dahl (ed) Human Comfort in Climate and Architecture”. P: 23-33.
[7] Kayode Komolafe, L & O. A. Akingbade, Folorunso. (2004), “Analysis of thermal comfort in Lagos, Nigeria”. Global Journal of Environmental Sciences.

2.6 Thermal Performance

Energy utilization in buildings is affected by many aspects; one of the most important aspects is the thermal performance. It is essential to predict the thermal performance of building envelope through heat transfer mechanisms for both enhancing the indoor environment conditions using HVAC and estimating heating and cooling loads[1]. In this section, the study will focus on the concept of thermal performance and its effect on energy consumption and the different mechanisms of thermal transfer through building envelope.

2.6.1 Definition of Thermal Performance

Thermal performance of any building depends on the difference of temperature between the indoor environment in the building and the outdoor environment from surroundings. Temperature difference could be considered as the main core of heat flow which is responsible for the thermal quality of the building indoor environment. Thermal performance is defined as "the process of modeling the energy transfer between a building and its surroundings"[2].

2.6.2 Impact of Thermal Performance on Energy Consumption

Thermal performance of building envelope is associated with the energy consumption[3]. Energy consumption depends on heat transfer through building envelope components such as walls, windows, doors, etc. which forms the heat gain and loss conditions in the indoor environment so that it is considered the most important factor influencing thermal performance[4]. Both heating and cooling energy consumption are affected by many factors but the most important factor is the heat transfer coefficient of wall, followed by the building shape coefficient[5].

[1] Zain, Zainazlan; Taib, Mohd and Baki, Shahrizam (2007), "Hot and humid climate: prospect for thermal comfort in residential building".
[2] Nayak, J.K. and Prajapati, J.A. (2006), "Handbook on energy conscious buildings".
[3] Ghisi, Enedir and Massignani, Ricardo (2007), "Thermal performance of bedrooms in a multi-storey residential building in southern Brazil", P: 730–742.
[4] Lars S. S. (2013), "Heat Transmission Coefficient Measurements in Buildings Utilizing a Heat Loss Measuring Device". P: 3601-3614.
[5] Yu, Jinghua; Xu, Xinhua and Tian, Liwei (2011), "Effect of Envelope Design on Energy Consumption Respect to EETP Index".

2.7 Thermal Transfer Mechanism

Heat as one of the energy forms could be transferred between different objects due to the difference in temperature. The direction of heat transfer flows always from the objects of hotter temperature to the objects of the cooler temperature[1]. Conduction, convection and radiation are three mechanisms used in the passive solar buildings to manage and control the heat transfer through the indoor environment[2]. (see fig. 2-1)

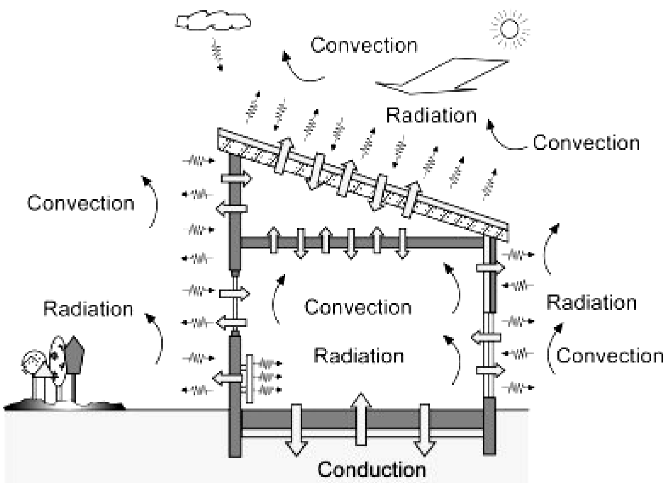

Figure 2-1 Heat transfer mechanisms
Source: Kuznik F. et al. (2015), "Integrating phase change materials (PCMs) in thermal energy storage systems for buildings".

2.8 Factors Affecting Thermal Performance of Buildings

A large number of factors could affect the thermal performance of a building. These factors where summarized as design variables, weather data, material properties and Building Occupancy and Operations[3]. These variables will be clarified as follows (see fig. 2-2):

[1] Roos, Carolyn (2008), "Principles of Heat Transfer, Energy Efficiency Factsheet".
[2] National Renewable Energy Laboratory 'NREL' (2006), "Zero Energy Buildings: A Critical Look at the Definition, ACEEE Summer Study"
[3] Nayak, J.K. and Prajapati, J.A. (2006), "Handbook on energy conscious buildings".

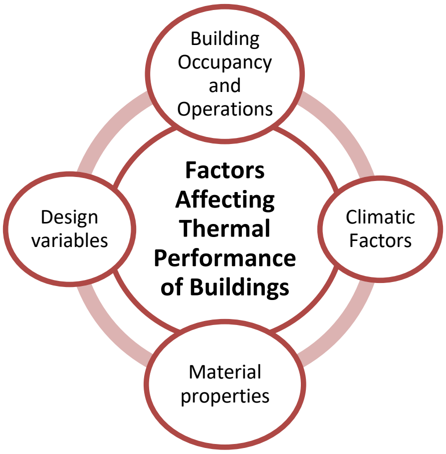

Figure 2-2 Factors affecting thermal performance of buildings
Source: Author.

2.9 Thermal Balance of Buildings

Heat transfer between buildings and environment which indicates to thermal performance of buildings is the main key to achieve thermal balance. The overall thermal transfer value OTTV is theorized as a measure of the amount of heat transfer from outside to the indoor environment through the external building envelope. Conduction through an opaque surface, conduction through glass window, solar radiation through glass window, the air exchange via ventilation or infiltration and the internal heat gains, are components of the heat gain which are responsible for thermal performance[1]. Thermal balance occurs when heat loss is equal heat gain from the different sources (conduction, ventilation, solar and internal gain). The sources of heat gain and loss will be discussed in this section (see fig. 2-3).

[1] Nikpour, Mansour; Zin kandar, Mohd; Ghasemi, Mohsen and Fallah, Hossein (2011), “Study of the Effectiveness of Solar Heat Gain and Day light Factors on Minimizing Electricity Use in High rise Buildings”. P: 73- 77.

Figure 2-3 Factors affecting thermal balance of buildings.
Source: Author.

2.10 Heat Regulation in Nature

Organisms and creatures in different nature systems use many ways to achieve appropriate thermal performance for adapting with the surrounding climate conditions. Either Nature or buildings try to provide a suitable temperature for occupant comfort. Both natural systems and buildings face the same challenges in terms of heat regulation. Nature uses many strategies and mechanisms for heat gain, dissipation, prevention and retention[1],[2] (see fig. 2-4).

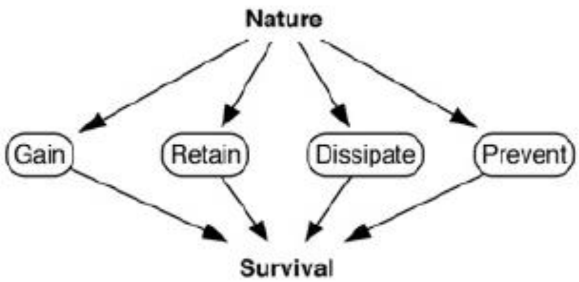

Figure 2-4 Heat Regulation in Nature.
Source: Lidia B. (2015), "A Biophysical Framework of Heat Regulation Strategies for the Design of Biomimetic Building Envelopes". P: 4.

[1] Schmidt-Nielsen, K., (2007), "Animal physiology: adaptation and environment".
[2] Simonis, P., et al. (2014), "Radiative contribution to thermal conductance in animal furs and other woolly insulators" P: 40-51.

2.11 Nature Based Framework for Heat Regulation

The previous heat regulation strategies which are found in nature could be presented in systematic framework. The framework concentrates on how organisms use different processes to adapt and carry out their functions in terms of heat regulation. The purpose of this framework is to search for any possible methodologies for the design solutions. It represents the relationship between thermoregulation in building and nature. It is divided into four main categories which are functions which represent the challenges of heat regulation in buildings, processes which represent different ways for design solutions, factors which represent properties of buildings components and pinnacles which represent the examples of various organisms and systems[1].

In nature organisms managed to solve the equation between heat gain and loss for providing a sufficient heat regulation balance without any conflict. Organisms use different methodologies to control the heat gain, retention, dissipation and prevention which are accomplished by physiological, behavioral, and morphological means. The understanding of heat regulation in nature leads to more capabilities for enhancing thermal performance. The study of heat regulations in nature presented in the following framework which focuses on various strategies for heat solutions which used by organisms[2] (see fig. 2-5).

[1] Badarnah, Lidia.(2015), “A Biophysical Framework of Heat Regulation Strategies for the Design of Biomimetic Building Envelopes”.
[2] Ibid.

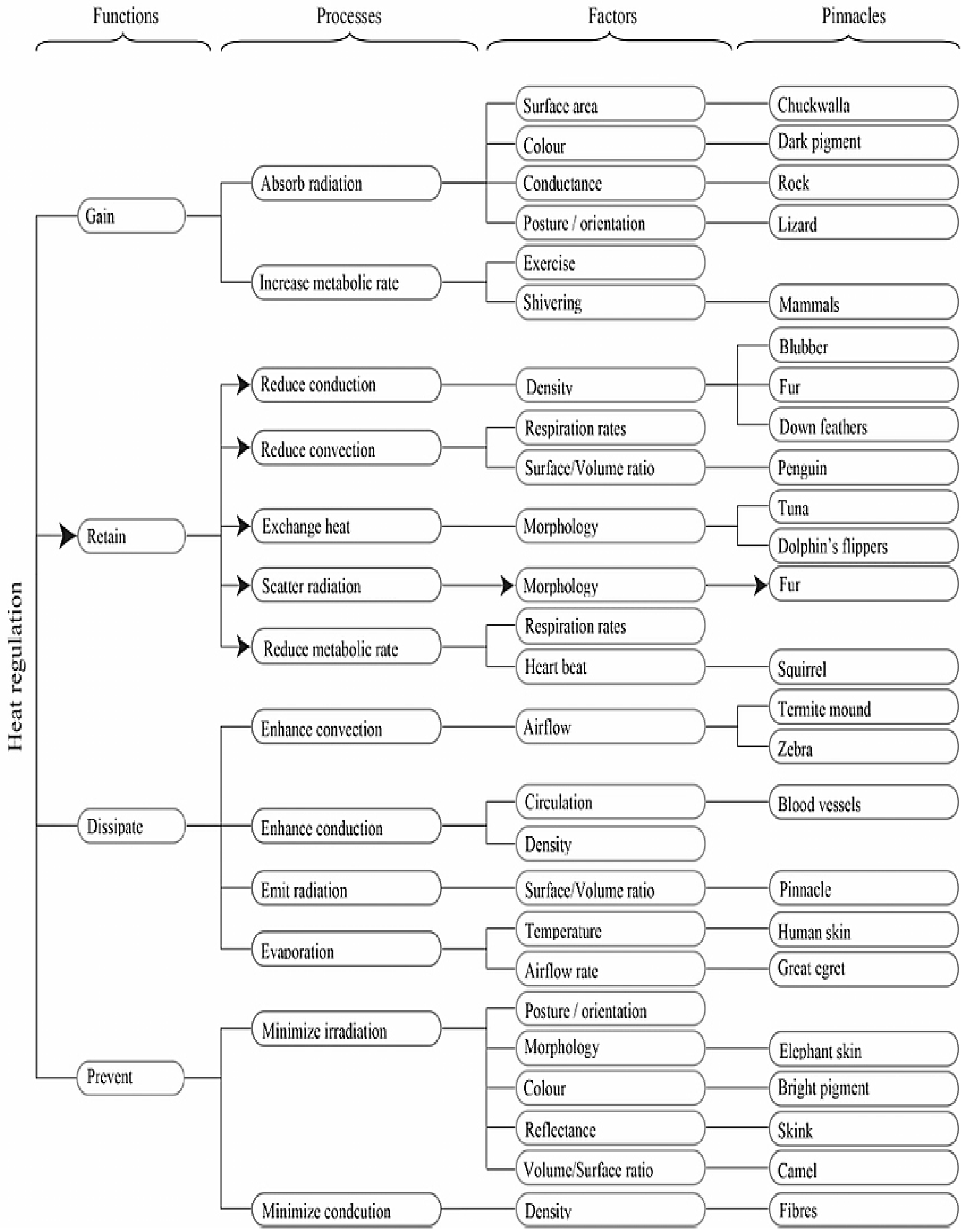

Figure 2-5 Nature based framework for heat regulation
Source: Lidia B. (2015), "A Biophysical Framework of Heat Regulation Strategies for the Design of Biomimetic Building Envelopes". P: 8.

2.12 Summary

Building envelope is the defense line of indoor environment in the inevitable confrontation with the surrounding outdoor environment. It is essential to guarantee and control the quality of indoor environment. It has various functions which affect the whole building such as providing sufficient rates of solar, thermal, fire resistance, acoustic, moisture level and indoor air quality. There are also impacts of building envelope which derive the sustainability of buildings. These impacts could be categorized in environmental, functional, social and economic impacts. Building envelope is a primary factor in achieving thermal comfort for the quality of indoor environment of buildings.

Thermal performance is the formulation of energy transfer between both indoor and outdoor environments. It has a great impact on energy consumption in buildings as it can manipulate on different and essential aspects of buildings. There are different mechanisms for thermal performance which are conduction, convection and radiation.

Thermal performance of buildings has many factors which manipulate in its rates such as design variables, material properties, climatic factors and finally building occupancy and operations. Each building has a state of thermal balance depending on five pillars that formulate the comfortable state of balance. The five pillars could be categorized as envelope thermal transfer value, heat transfer rate via ventilation, building’s solar heat gain, building’s internal heat gain and evaporation heat loss. In nature, organisms perform many strategies to manage thermal performance through its body.

The natural strategies are used for heat gain, dissipation, prevention and retention indicate that thermal performance is a fundamental factor of life for each organism in nature and as well buildings and built indoor environment. Organisms in nature managed to formulate their abilities in order to reach the thermal balance state which is essential to survive in harsh environmental conditions.

The studying and understanding for heat regulation in nature occurs by organism strategies led to find innovative solutions for building to control thermal performance for achieving thermal comfort rates. The inspiration of nature strategies depends on the main idea of biophilia effect between human and nature. It is important to understand well this relation between human and nature in order to generate successful solutions for thermal performance in buildings, so the next chapter will be focused on biophilia effect.

2.13 Conclusion

Building envelope is the shield of buildings against outer circumstances. Sustainability of buildings depends on building envelope effects such as environmental, social, functional, and economic effects. Thermal balance, one of the recognized environmental effects of building envelope on sustainability, could be achieved in buildings by controlling thermal performance of building envelope. There are many factors could be used by architects to maximize the use of thermal performance such as design variables, material properties, climatic factors, and building occupancy. The research concentrates on design variables of building envelope to use for enhancing thermal performance of building envelope (see fig. 2-6).

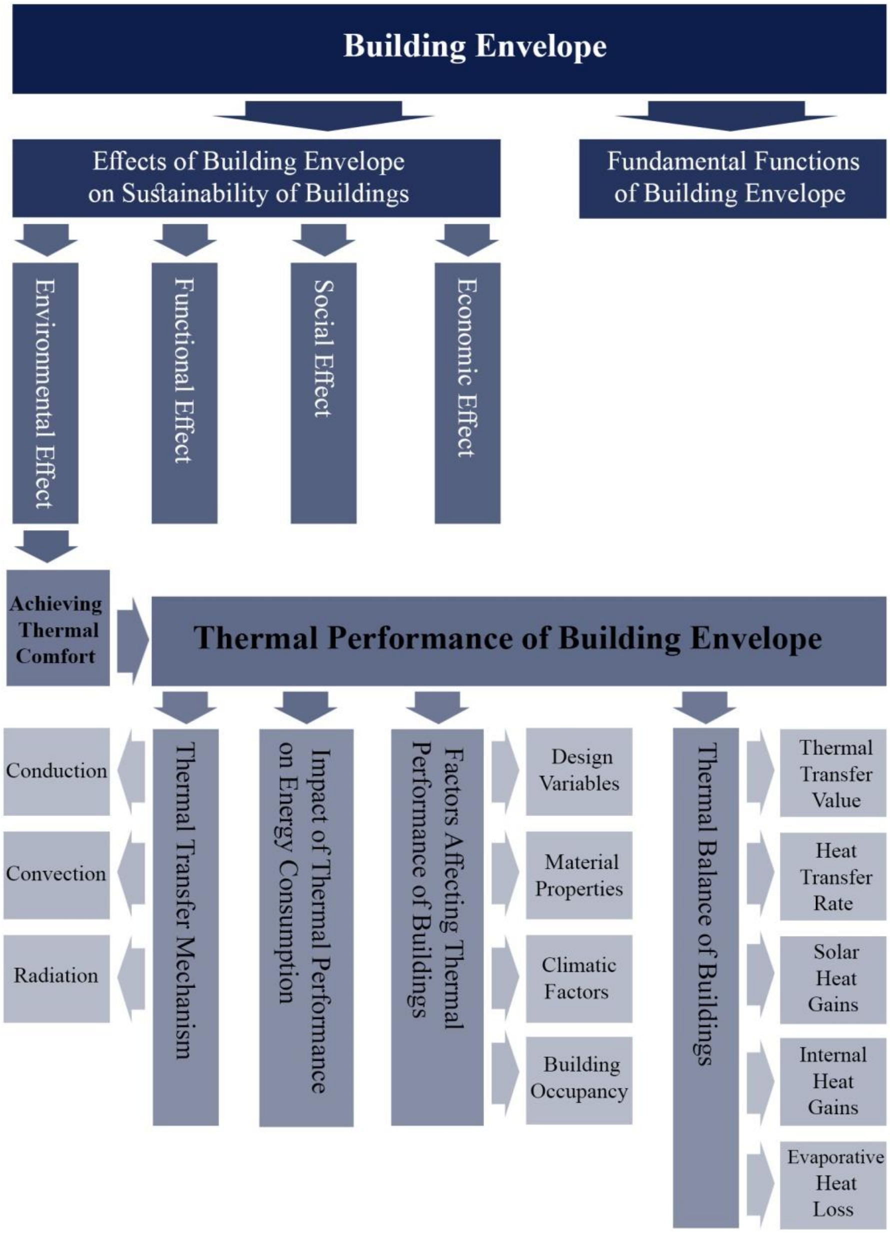

Figure 2-6 Chapter Two Conclusions
Source: Author.

Chapter Three
Biomimicry In Architecture

Chapter Three
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Biomimicry In Architecture

Chapter Three
Biomimicry in Architecture

3.1 Introduction

In this chapter, the research concentrates on biophilia effect, biophilic design patterns and qualities. One of biophilic design patterns, Biomimicry, depends on the inspiration from nature to solve problems. Biomimicry has many approaches and levels which architects could use to solve many environmental problems. Biomimicry applications could be used in architecture through inspiration from three sources which are forms of natural organisms, forms of structures in nature, and materials owned by natural organism. The research presented many design strategies are inspired from biomimicry.

3.2 Biophilia Effect Definition

Biophilia effect is "the effect that describes the link between nature and humans which is an innate and genetically determined affinity of human beings with the natural world"[1]. According to E.O. Wilson (1984) [2], Biophilia meaning implies that human beings love nature by instinct. Human beings as biological beings are in need of nature to afford and improve their emotional and physical health. By understanding the concept of biophilia effect in nature many natural phenomena could be explained such as how human beings admire crashing waves and crackling fires, how creativity could be enhanced by garden view, how heights and shadows can imply fear feeling[3].

3.2.1 Preceding Studies of Biophilia Effect

Biophilia effect has been studied by many scientific researches in the last decades. In 2013, Dr. George M. and Susana M. carried out a study about how different factors such as health, psycology, economics, and conservation could affect the link between wellbeing and environmental aspects. The study was carried out through self-reported

[1] https://en.oxforddictionaries.com. Last accessed 20th November, 2019.
[2] Wilson E. O. (1984), "Biophilia".
[3] Kellert, S., Heerwagen, J., Mador, M. (Ed.). (2008), "Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life".

responses of more than 20,000 participants within the UK and abroad. The results of the study indicate that participants are significantly and substantially happier outdoors in all green or natural habitat types than they are in urban environments[1].

Another important study was carried out by Elzeyadi I. (2017) revealed that “Workers in offices with poor ratings of light quality and in offices with poorer views used significantly more sick leave hours. Taken together, the two variables explained 6.5% of the variation in sick leave use, which was statistically significant. The implications of these findings are huge when one considers productivity and health insurance costs these sick leave hours can affect to an organization”[2].

Many questions from clients and designers arise about how to achieve the relation between nature and built environments. They ask about the best strategy to present this relation and wonder if this strategy may proceed with installations of real nature or mimic with reproduced objects and images from nature. Several studies by Salingaros N. et al. (2008)[3], Biederman I. and Vessel E. (2006)[4], Kellert S. (2005)[5], Harris K. (2012)[6], and Browning W. et al. (2012)[7]. The previous studies revealed the empirical findings on psychological advantages of natural environments and environments mimicking their geometrical qualities on human wellbeing.

3.2.2 Qualities of Biophilia Effect

Biologist Boyden S. (1971) made many researches in the field of natural environment effect and defines the optimum healthy environment as “the conditions, which tend to "promote or permit the optimal physiological, mental, and social performance in its natural or

[1] George, M., Susana M. (2013), “Happiness is Greater in Natural Environments”. P: 992-1000

[2] Elzeyadi I. (2019), “Daylighting-Bias and Biophilia: Quantifying the Impact of Daylighting on OccupantsHealth”.

[3] Salingaros, N., Masden, K. Neuroscience. (2008), “The Natural Environment, and Building Design. In Kellert, Stephen R., Heerwagen, Judith and Mador, Martin (Ed.), Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life”. P: 59-83.

[4] Biederman, I. & Vessel, E. A. (2006), “ Perceptual Pleasure and the Brain”. P: 247-253.

[5] Kellert, S. (2005), “Building for life: Understanding and designing the human-nature connection”. 2005.

[6] Harries, K. (2012), “The Ethical Function of Architecture”.

[7] Browning, W. D., Kallianpurkar, N., Ryan, C. O., Labruto, L., Watson, S., Knop, T. (2012), “The Economics of Biophilia”.

'evolutionary' environment"[1]. According to Boyden's point of view, environments need to fully satisfy both "survival needs" and "well-being needs". Boyden S. (1971) determined the criteria that should be forwarded to satisfy these needs in the built environment as the following[2]:

a. Think beyond survival to well-being
b. Build on "primitive preferences" and connections to Nature
c. Design for the senses as well as the body.

According to the studies of Salingaros et al. (2008) in this field, the presence of these qualities in the environment is very important for people because it strengthens both the sense of belonging and wellbeing and the feeling of existing as a main source of "neurological nourishment"[3]. The strategy of the neurological nourishment was revealed by neurological studies. The most important conclusion from these studies was that human have an innate nostalgia for certain type of information that is connected with the brain's pleasure centers, which from other side has an effect on the dominance of reduction of pain[4].

3.3 Biophilic Design Concept

E. O. Wilson (1984) developed the concept of biophilic design and explained it as "an acknowledged the advantages of forms inspired by biological structures, but in a more profound way than simple mimicry"[5]. According to William B. et al. (2014), patterns of biophilic design are presented according to the ability of supporting Cognitive performance, stress reduction, emotion and mood enhancement and human body wellbeing[6]. The proposed ideas of E. O. Wilson were developed and connected with the architectural design by cooperation between Kellert, S. et al. (2008) in a book named "Biophilic Design" in which Kellert, S. et al. explained the relation

[1] Boyden S., (1971), "Biological Determinants of Optimal Health in The Human Biology of Environmental Change by D.J.M. Vorster (Ed.)".
[2] Ibid.
[3] Salingaros, N., Masden, K. Neuroscience. (2008), "The Natural Environment, and Building Design. In Kellert, Stephen R., Heerwagen, Judith and Mador, Martin (Ed.), Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life". P: 59-83.
[4] Biederman, I. & Vessel, E. A. (2006), " Perceptual Pleasure and the Brain". P: 247-253.
[5] Wilson E. O. (1984), "Biophilia".
[6] William B., Catherine R., Joseph C. (2014), "14 Patterns of Biophilic Design, Terrapin Bright Green". P: 9-12.

between biophilia and design. According to Kellert, S. et al. (2008), there are several concepts and suggestions of qualities and characteristics of spaces which could satisfy the human needs to associate with Nature. The main Concept which Kellert S. et al. (2008) suggested was the qualities of biophilic design which form and indicate to the biophilia effect in the built environment. Kellert S. et al. (2008) defined the biophilic design qualities as follows[1]:

a. Prospect: brightness, wide horizons, or ability to see into a distance.
b. Refuge: sense of enclosure and shelter with canopy effect or branch-like forms overhead.
c. Livability and movement: with real moving water or reflecting surfaces.
d. Biodiversity: vegetation elements or symbolic representation of them (trees, plants, or flowers).
e. Sensory variability (or ephemeral qualities of space): changes and variability in environmental color, temperature, air movement, light, texture…etc.
f. Fractals: self-similarity, natural patterns or cycles, hierarchal characteristics.
g. Sense of playfulness: elements that aim at delight, surprise, or dazzle.
h. Enticement: complexity and richness of details to be seen, or gradual openness of views.

3.4 Patterns of Biophilic Design

According to Kellert S. et al. (2008) studies of biophilic design, biophilic design effect on human health and performance as it can minimize stress, improve cognitive function, wellbeing, accelerate healing and creativity. Biophilic design could be formulated in a framework for promoting the corporation between qualities and strategies of it in the built environment. In biophilic design framework, biophilic design could be classified in three main categories which are: Nature in the Space, Natural Analogues, and Nature of the Space[2].

[1] Kellert, S., Heerwagen, J., Mador, M. (Ed.). (2008), "Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life".
[2] William B., Catherine R., Joseph C. (2014), "14 Patterns of Biophilic Design, Terrapin Bright Green". P: 9-12.

Each group contains patterns of biophilic design which could be fulfilled in the built environment (see fig. 3-1).

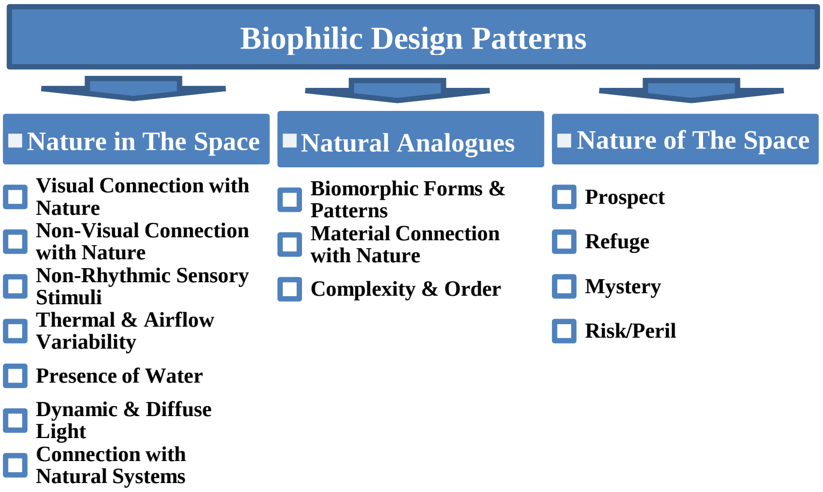

Figure 3-1 Patterns of Biophilic Design
Source: Author.

3.4.1 Nature in the Space

This category represents the physical, direct and ephemeral presence of nature in space. This presence could be achieved by various elements such as water, animals, plant life, sounds, breezes and any other natural elements. The implementation of this category could appear in many forms such as potted plants, butterfly gardens, fountains, flowerbeds, aquariums, green walls, courtyard gardens, vegetated roofs and water features. The designer can provide the building with a strong nature in space experience when he provide his design with the creation of direct and meaningful connections with natural elements specially through variety movement and multi-sensory interactions. Nature in the Space category includes seven biophilic design patterns as follows:

- Visual Connection with Nature: A view to elements of nature, living systems and natural processes.
- Non-Visual Connection with Nature: Auditory, haptic, olfactory, or gustatory stimuli that engender a deliberate and

positive reference to nature, living systems or natural processes.

- Non-Rhythmic Sensory Stimuli: Stochastic and ephemeral connections with nature that may be analyzed statistically but may not be predicted precisely.
- Thermal & Airflow Variability: Subtle changes in air temperature, relative humidity, airflow across the skin, and surface temperatures that mimic natural environments.
- Presence of Water: A condition that enhances the experience of a place through seeing, hearing or touching water.
- Dynamic & Diffuse Light: Leverages varying intensities of light and shadow that change over time to create conditions that occur in nature.
- Connection with Natural Systems: Awareness of natural processes, especially seasonal and temporal changes characteristic of a healthy ecosystem.

3.4.2 Natural Analogues

This category represents organic, indirect and non-living evocations of nature. This presence could be achieved by various elements such as shapes, objects, sequences, patterns, colors and materials found in nature. These elements could be found in the built environment as furniture with organic shapes, artwork from shells and leaves, textiles with natural materials and ornamentations. All these elements represent the indirect connection with nature while in fact they are only analogous of the items in their ‘natural’ state. The strongest Natural Analogue experiences are achieved by providing information richness in an organized and sometimes evolving manner. Natural Analogues category includes three patterns of biophilic design as follows:

- Biomorphic Forms & Patterns: Symbolic references to contoured, patterned, textured or numerical arrangements that persist in nature.
- Material Connection with Nature: Materials and elements from nature that, through minimal processing, reflect the local ecology or geology and create a distinct sense of place.
- Complexity & Order: Rich sensory information that adheres to a spatial hierarchy similar to those encountered in nature.

3.4.3 Nature of the Space

This category represents spatial configuration in nature. This presence could be achieved by our innate and desire to be able to see beyond the environment around us such as when we are fascinated with the slightly dangerous or unknown or views and blocks of revelation or even the fear feelings. The cooperation between spatial configurations and with patterns of Nature in the Space and Natural Analogues enhances nature of space experiences. Nature of space category includes four patterns of biophilic design as follows:

- Prospect: An unimpeded view over a distance, for surveillance and planning.
- Refuge: A place for withdrawal from environmental conditions or the main flow of activity, in which the individual is protected from behind and overhead.
- Mystery: The promise of more information, achieved through partially obscured views or other sensory devices that entice the individual to travel deeper into the environment.
- Risk/Peril: An identifiable threat coupled with a reliable safeguard.

3.5 Biomimicry Concept

In architecture, concepts and ideas could be derived from many sources. One of the most important sources is inspiration from nature. Biology, biochemistry, pharmaceuticals, and material scientists use the term biomimicry to represent the process of inspiration from nature. All these fields seek for properties in natural systems and living organisms which can serve as inspiration sources according to scientist's observations and analysis. Scientists transform the analysis of living organisms' properties to practical product in many fields such as industrial, biological and medical products. However it is not considered as a new source of concepts and ideas in architecture as it has been used for many times, but it can be considered a new approach to implement the inspiration from nature.

Biomimicry is the examination of nature, its models, systems, processes, and elements to emulate or take inspiration from in order to solve human problems. The term biomimicry and biomimetic come from the Greek words bios, meaning life, and mimesis, meaning to imitate. Other terms often used such as bionics, bio-inspiration, and biogenesis[1].

In information technology age, biomimicry as a design approach indicates to the re-examination of nature using new digital tools of technology and science. However, it is very important to discuss the history of using biomimicry in architectural design. Before the word biomimetic existed, Joseph Paxton had used biomimicry in his induction from water lilies. He noticed the leaf structure of water lilies and concluded that it has a radial structure with cantilever system. Dennis D. (2005) developed an architectural system of furrows and ridges which was like a self-reinforced truss in order to form the frame of Chatsworth's great greenhouse[2].

Although many forms of biomimicry as an architectural design method are discussed by researchers and professionals in sustainable architecture field[3],[4], the practical application of biomimicry still largely unrealized, as demonstrated by the small number of built case studies[5]. While many designers and scientists use biomimicry specifically as a method to maximize the sustainability of what they have created, biomimicry is also used in many cases as a source of novel innovation[6],[7].

3.5.1 Approaches to Biomimicry

Design Approaches which use biomimicry as a design methodology could be categorized into two main categories. The first category calls for defining human needs in spaces or indicate the design problem then seeks to the way living organisms or natural systems use to solve environmental problems. The first category could be termed as design looking to biology. The second category calls for recognizing behavior, function and characteristics in an organism or ecosystem then use the projection of these acts into architectural design to achieve

[1]http://environment-ecology.com.
[2]Dennis Dollens, (2005), "Toward Biomimetic Architecture".
[3] Reed, B. (2006), "Shifting our Mental Model - "Sustainability" to Regeneration".
[4] Berkebile, B. (2007), "Master Speaker Address. Living Future Conference".
[5] Faludi, J. (2005), "Biomimicry for Green Design (A How To) World Changing".
[6] Baumeister, D. (2007), "Evolution of the Life's Principles Butterfly Diagram".
[7] Reap, J., Baumeister, D. & Bras, B. (2005), "Holism, Biomimicry and Sustainable Engineering".

its benefits. The second category could be termed as biology influencing design[1].

3.5.1.1 First Approach: Design looking to biology

In this approach, designers search in the surrounding nature in order to find solutions which are required in the design process. Foremost, Designers should identify the existing problems then biologists tend to find the suitable treatment of a living organism or natural system that treats similar problems. Designers identifying initial goals and parameters for the design from early stages of design process use this approach effectively (see fig. 3-2).

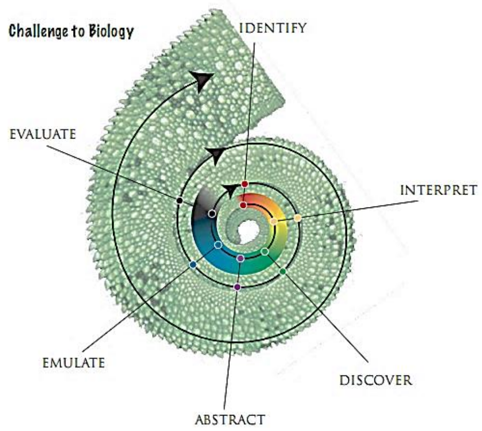

Figure 3-2 Design Spiral for Design Looking to Biology Approach
Source: John Y. (2011), "Biomimetic Building Skin: A Phenomenological Approach Using Tree Bark As Model". P: 3.

Daimler Chrysler's prototype Bionic Car design uses this approach in the designing process. The designers were looking for a car with large volume and small wheels. They search in the living world and found the box fish (ostracion meleagris) which a surprisingly aerodynamic fish is given its box like shape. Designers built the chassis and structure of the car by biomimicry concept inspired from boxfish using computer applications[2] (see fig. 3-3).

[1] Biomimicry Guild (2007), "Innovation Inspired by Nature Work Book".

[2] Vincent, J. F. V., et al. (2006), "Biomimetics - its practice and theory".

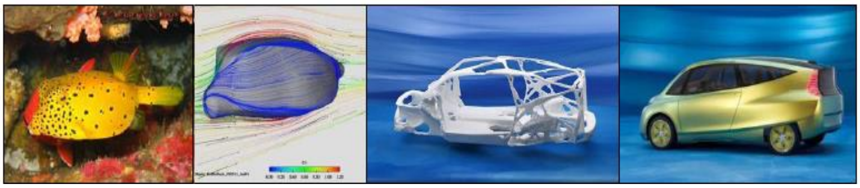

Figure 3-3 Daimler Crysler bionic car.
Source: Phil R. (2010), "Fitness for the Future: Applying Biomimetics for Business Strategy". P: 57.

3.5.1.2 Second Approach: Biology Influencing Design

In this approach designers search for solutions by understanding and defining the characteristics of natural organisms or ecosystem behavior, life principles and composition in order to find main guidelines for successful natural treatments. In design process, designers tend to apply this guideline in their designs to have similar results (see fig. 3-4).

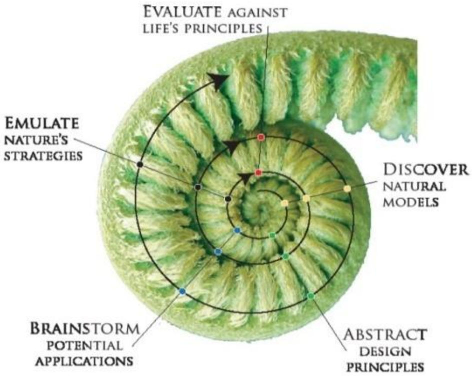

Figure 3-4 Design Spiral for Biology Influencing Design
Source: Hanaa L. (2009), "Biomimetic Architecture". P: 6.

One of the most important examples of the use of this approach is the analysis of lotus flower self-cleaning strategy. The scientific analysis of how lotus flower always has a clean surface and how it resists dirty from swampy water from surrounding environment. Designers use these characteristics of lotus flower surface as an inspiration source to produce lotusan paints which enables building to be having self-cleaning walls[1] (see fig. 3-5).

[1] Baumeister, D. (2007), " Biomimicry Presentation at the University of Washington College of Architecture".

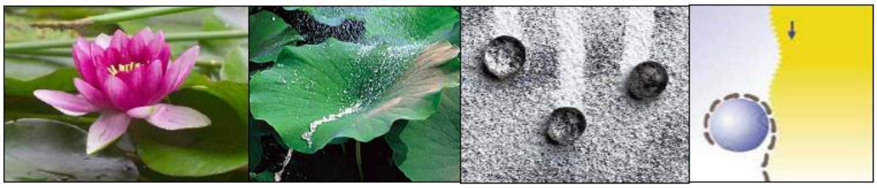

Figure 3-5 Lotus Inspired Lotusan Paint
Source: Pedersen Zari, M. (2007), "Biomimetic Approaches to Architecture".P: 3.

3.5.2 Biomimicry Levels

Biomimicry has three levels which may be used in solving design problems within the two approaches of biomimicry discussed before. The three levels of biomimicry are organic level, behavior level and ecosystem level. Many researches have been done in this field to identify the differences between the three levels of biomimicry and maximize the capabilities and potentials of biomimicry as a design methodology to improve the sustainability and optimize the solutions in the built environment. The three levels of biomimicry could be clarified through the framework for biomimicry applications. This framework is useful for both design looking to biology and biology influencing design approaches[1].In biomimicry level framework, each level is described in terms of five indicators which are connected to the level principle. According to the framework, the design could be mimicked in terms of what it looks like (form), what it is made out of (material), how it is made (construction), how it works (process) or what it is able to do (function).

3.5.2.1 Organism Level (Nature as Model)

This level of biomimicry indicates to the organism itself as biomimicry could be inspired by mimicking a part of the organism or the whole organism[2]. The living organisms' species in nature represent evolving generations which have been passed various evolving periods for millions of years. Now those generations found in nature already have the survival strategies which developed and adapted through the time to resist environmental circumstances through ages (see tab. 3-1).

[1] Biomimicry Guild (2007), "Innovation Inspired by Nature Work Book".

[2] Pedersen Zari, M. (2007), "Biomimetic Approaches to Architecture".P: 4.

Table 3-1 Biomimicry Levels Framework.
Source: Pedersen Zari, M. (2007), "Biomimetic Approaches to Architecture".P: 3.

Level of Biomimicry		*Example - A building that mimics termites:*
Organism level (Mimicry of a specific organism)	*form*	The building looks like a termite.
	material	The building is made from the same material as a termite; a material that mimics termite exoskeleton / skin for example.
	construction	The building is made in the same way as a termite; it goes through various growth cycles for example.
	process	The building works in the same way as an individual termite; it produces hydrogen efficiently through meta-genomics for example.
	function	The building functions like a termite in a larger context; it recycles cellulose waste and creates soil for example.
Behaviour level (Mimicry of how an organism behaves or relates to its larger context)	*form*	The building looks like it was made by a termite; a replica of a termite mound for example.
	material	The building is made from the same materials that a termite builds with; using digested fine soil as the primary material for example.
	construction	The building is made in the same way that a termite would build in; piling earth in certain places at certain times for example.
	process	The building works in the same way as a termite mound would; by careful orientation, shape, materials selection and natural ventilation for example, or it mimics how termites work together.
	function	The building functions in the same way that it would if made by termites; internal conditions are regulated to be optimal and thermally stable for example (fig. 6). It may also function in the same way that a termite mound does in a larger context.
Ecosystem level (Mimicry of an ecosystem)	*form*	The building looks like an ecosystem (a termite would live in).
	material	The building is made from the same kind of materials that (a termite) ecosystem is made of; it uses naturally occurring common compounds, and water as the primary chemical medium for example.
	construction	The building is assembled in the same way as a (termite) ecosystem; principles of succession and increasing complexity over time are used for example.
	process	The building works in the same way as a (termite) ecosystem; it captures and converts energy from the sun, and stores water for example.
	function	The building is able to function in the same way that a (termite) ecosystem would and forms part of a complex system by utilising the relationships between processes; it is able to participate in the hydrological, carbon, nitrogen cycles etc in a similar way to an ecosystem for example.

As Baumeister D. (2007) stated "the research and development has been done"[1]. Therefore, designers have a huge umbrella of examples to pick solutions from it in order to solve problems experienced by society that organisms may have already addressed before and succeeded in solving it. This concept helps designers especially for

[1] Baumeister, D. (2007), " Biomimicry Presentation at the University of Washington College of Architecture".

climate change solutions and understanding the consequences of the negative environmental impact[1].

The Hydrological Center for the University of Namibia represents an example of organism level of biomimicry[2]. It depends of mimicking of the Namibian desert beetle, stenocara[3]. It has a characteristic by which the Droplets form on the hydrophobic rough surface of the beetle's back and wings and roll down into its mouth[4]. The surface of the beetle has been studied and mimicked to be used for other potential applications such as to clear fog from airport runways and improve dehumidification equipment for example[5],[6] (see fig. 3-6).

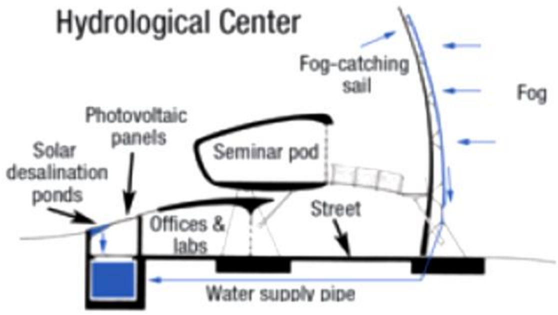

Figure 3-6 The Hydrological Center for the University of Namibia
Source: Michael J. M. (2012), "Biomimicry: Using Nature as a Model for Design".P:15.

Waterloo International Terminal designed by Nicholas Grimshaw & Partners is another example of organism level. The design of terminal form faces the problem of how it could respond the changes in air pressure as trains enter and depart the terminal. This flexibility of structure is found in the surface of Pangolin. The structure of the terminal is inspired from the shape of Pangolin body as it constructed from glass panels fixings that make up the structure mimic the flexible

[1] Alberti, M., Marzluff, J. M., Shulenberger, E., Bradley, G., Ryan, C. & Zumbrunnen, C. (2003), "Integrating Humans into Ecology: Opportunities and Challenges for Studying Urban Ecosystems". P: 1169-1179.
[2] Killeen, M. (2002), "Water Web".
[3] Garrod, R. P., Harris, L. G., Schofield, W. C. E., McGettrick, J., Ward, L. J., Teare, D. O. H. & Badyal, J. P. S. (2007), "Mimicking a Stenocara Beetle's Back for Microcondensation Using Plasmachemical Patterned Superhydrophobic- Superhydrophilic Surfaces". P: 689-693.
[4] Parker, A. R. & Lawrence, C. R. (2001), "Water capture by a desert beetle". P: 14-33.
[5] Ravilious, K. (2007), "Borrowing from Nature's Best Ideas".
[6] Knight, W. (2001), "Beetle fog-catcher inspires engineers". P: 13-38.

scale arrangement of the Pangolin so they are able to move in response to the imposed air pressure forces[1] (see fig. 3-7).

Figure 3-7 Waterloo International Terminal
Source: Pedersen Zari, M. (2007), "Biomimetic Approaches to Architecture". P: 5.

3.5.2.2 Behavior Level (Nature as Measure)

The same environmental conditions face humans and organisms and both of them need to find suitable solutions to encounter these issues. These organisms tend to adapt and survive within environmental abilities of a specific place and within limits of energy and material availability. The environmental limits which create ecological adaptations in ecosystems ensure that not only well-adapted organisms continue to evolve, but also well-adapted organism behaviors and relationship patterns between organisms or species[2].
Eastgate Building in Harare, Zimbabwe and the CH2 Building in Melbourne, Australia designed by Mick Pearce represent two examples of behavior level of biomimicry. The design of these buildings depends on the passive ventilation and temperature regulation strategies which were inspired from termite mounds, in order to create a thermally stable interior environment. In CH2 building, the treatment of water which is mined from the sewers under the building is inspired from the way in which the termite will use the proximity of aquifer water as an evaporative cooling mechanism (see fig. 3-8).

[1] Aldersey-Williams, H. (2003), "Zoomorphic - New Animal Architecture".
[2] Reap, J., Baumeister, D. & Bras, B. (2005), "Holism, Biomimicry and Sustainable Engineering".

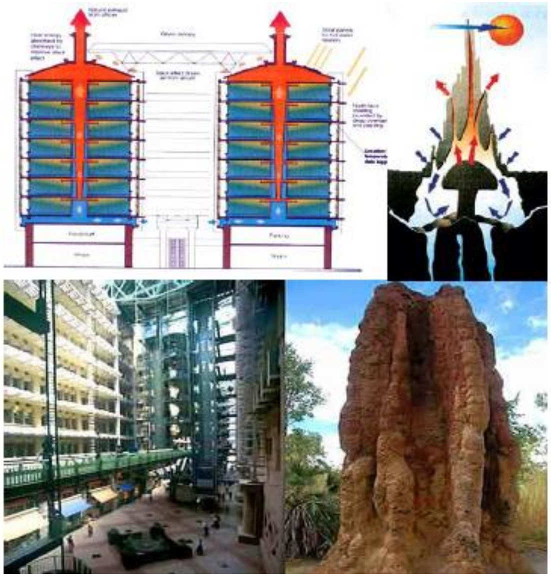

Figure 3-8 Eastgate Building in Zimbabwe and the CH2 Building in Australia
Source: Michael J. M. (2012), "Biomimicry: Using Nature as a Model for Design".P:22.

3.5.2.3 Ecosystem Level (Nature as Mentor)

Benyus (1997) and Vincent (2007) described the ecosystem level which is the third level of biomimicry as an integral part of biomimicry[1], while Lourenci et al. (2004), and Russell (2004) used the term ecomimicry to describe the ecosystem biomimicry in design[2],[3]. The main advantage of ecosystem level is that it can cooperate with the other two levels of biomimicry organism and behavior levels. In this level it can be also possible to incorporate existing established building methods that are not specifically biomimetic with biomimetic methods, where human and organism systems are merged to the achieve the required needs in these buildings.

Master plan of Zera Island located in Azerbaijan's capital Baku, on The Caspian Sea. It was designed by Bjarke Ingels, founder of BIG architects. Zera Island master plan represents an example of ecosystem level of biomimicry. It was designed to perform as a zero energy city.

[1] Benyus, J. (1997), "Biomimicry - Innovation Inspired by Nature".
[2] Lourenci, A., Zuffo, J. A. & Gualberto, L. (2004), "Incipient Emergy Expresses the Self-Organisation Generative Activity of Man-Made Ecomimetic Systems".
[3] Russell, J. A. (2004), "Evaluating the Sustainability of an Ecomimetic Energy System: An Energy Flow Assessment of South Carolina".

Master plan area equals 1,000,000m² so the challenges of this project were difficult relating to the area of this project. The location of Azerbaijan is called as the Alps of Central Asia. The proposed concept for Zera Island city master plan was inspired from the mountains of Azerbaijan. Each building in master plan not only reflects the inspiration from one of the seven most famous mountains in Azerbaijan, but they are all also inhabitable. BIG Architects managed to generate enough energy for buildings thanks to new sustainable techniques[1].

Wind turbines located in the Caspian Sea used to generate wind energy. The resulted wind energy used to supply desalination plants stations with energy. These desalination plants are used to produce fresh water by extracting salt from sea water and turn sea water to fresh and suitable water for human use. Water could be used also in heating and cooling actions in built environment. Landscape areas benefit the waste water that results from buildings usage. Storm water in Zera Island is also collected and used in plants irrigation. There are large amounts of solid waste results from the previous phases of extracting, producing, and using water which are used in fertilizing the soil for enhancing soil quality [2] (see fig. 3-9).

Figure 3-9 Zira Island Master Plan
Source: Michael J. M. (2012), "Biomimicry: Using Nature as a Model for Design".P:25.

[1] Michael J. M. (2012), "Biomimicry: Using Nature as a Model for Design".P:24.
[2] Michael J. M. (2012), Ibid.P:25.

3.6 Biomimicry Applications

Many types of biomimicry applications are presented to emphasis the capabilities and importance of using biomimicry as an approach to design with nature. Neal Panchuk presented three types of forms in nature could be act as an inspiration source from nature for biomimicry[1]. Three types of forms include that Forms of Natural Organisms Composition, Forms of Built Structures by Organisms and Materials Owned by Natural Organisms.

3.6.1.1 Forms of Natural Organisms Composition

The form and shape composition of the organisms in nature have a wide range of difference which provide designers with a huge number of opportunities for picking the inspiration for biomimicry. The complex forms and shape of any organism could be divided and abstracted to basic shapes which the organism use them in different ways and proportions in order to formulate the organism's structure[2]. Some of the examples of using forms and shapes in nature as inspiration sources for biomimicry are declared as following (see fig. 3-10):

- Stones embedded in matrices – Worm tubes (concrete)
- Spirals – Sunflowers, shells, horns of wild sheep, claws of the canary bird (domed roofs)
- Curved shells – Skulls, eggs, exoskeletons (domed roofs)
- Parabolic Forms – Tardigrade (pneumatic structures
- Corrugated structures – Scallop shells, cactus plants, stiffness without mass (doors, packing boxes, aircraft floors, roofs)
- Columns – Tree trunks, long bones, endoskeletons (posts)

[1] Neal P. (2006), "An Exploration into Biomimicry and its Application in Digital & Parametric (Architectural) Design".
[2] Tsui, E. (1999), "Evolutionary architecture - nature as a basis for design".

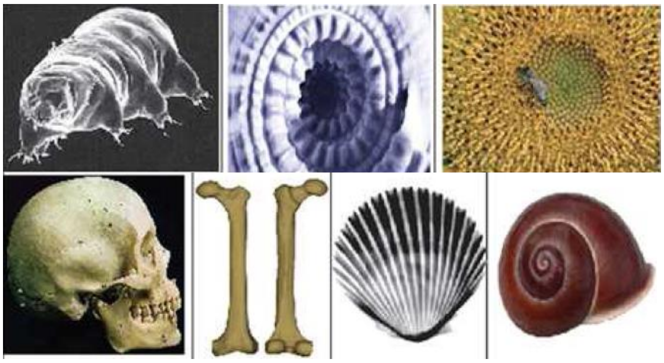

Figure 3-10 Some of organism's Components in Nature.
Source: Neal P. (2006), "An Exploration into Biomimicry and its Application in Digital & Parametric [Architectural] Design". P: 19.

There are many buildings use forms of natural organism's composition. Some examples of this category will be discussed as follows:

I. <u>European Central Bank</u>

The form of European Central Bank designed by NOX was inspired from Radiolaria (microorganisms around 0.1 mm in size). "The amazingly beautiful drawings of Ernst Haeckel from the early 1900s and the research of Helmcke and Otto throughout the second half of the twentieth century show that Radiolaria are of a highly architectural nature"[1]. The concept of form morphology depends on that the isomorphism is not fatally attracted to the Sphere but is the generator of ribs, spikes, creases and tubes of Radiolaria (see fig. 3-11).

[1] Spuybroek, Lars. (2004), "ECB. In NOX machining architecture".

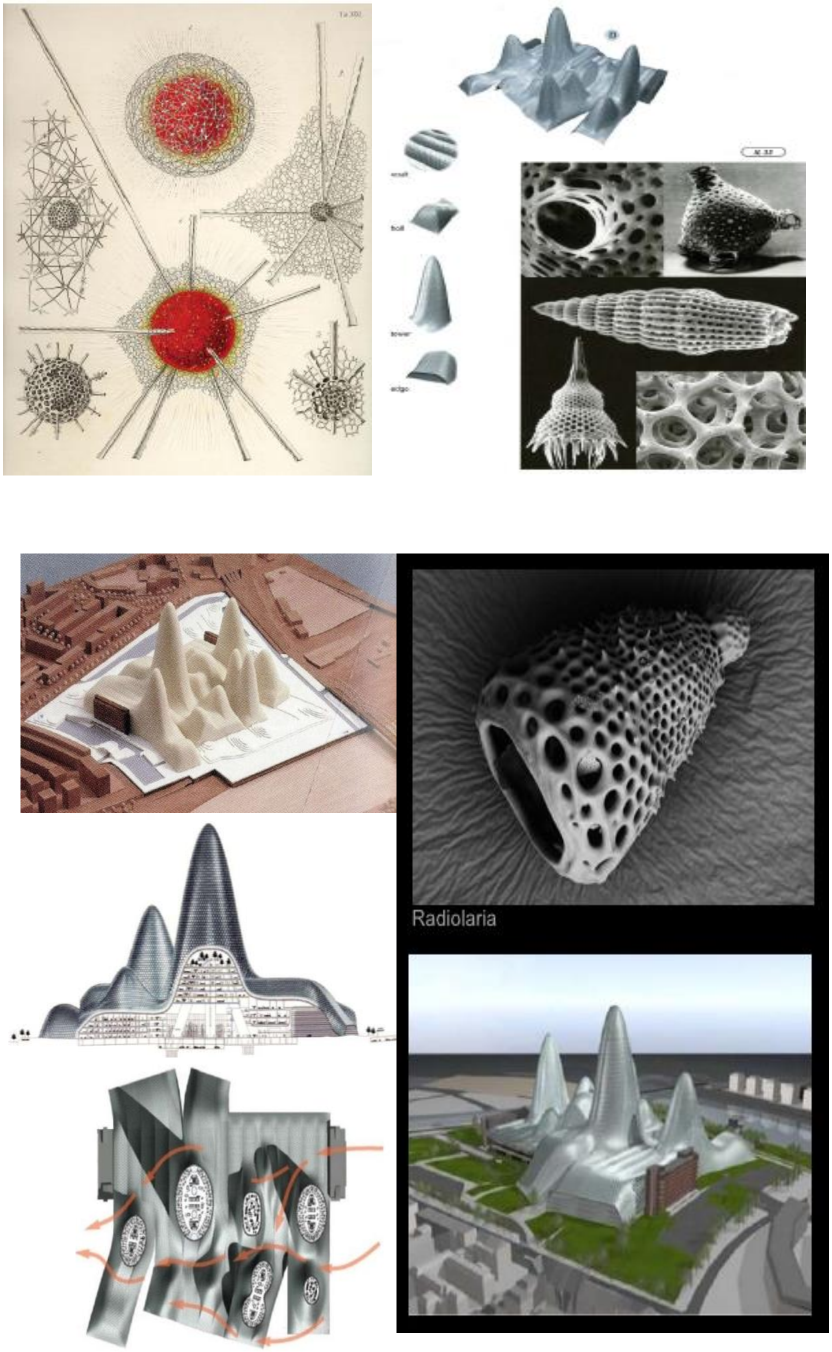

Figure 3-11 NOX: Design based on Radiolaria morphology.
Source: Neal P. (2006), “An Exploration into Biomimicry and its Application in Digital & Parametric [Architectural] Design”. P: 38.

II. Lyon-Saint Exupery Airport Railway Station

The building designed by Santiago Calatrava looks like a bird tends to fly into sky. The central hall airport railway station was covered by a structure inspired from a moment of a bird at the point of flight. The biomimicry of birds shape in this moment reflects the stability and balance which recognized in this moment. The central hall has a span of 394 feet and its roof is covered by four arches with a curved, tapering, arched spine[1] (see fig. 3-12).

Figure 3-12 Lyon-Saint Exupery Airport Railway Station. Source:https://calatrava.com/projects/lyon-saint-exupery-airport-railway-station-colombier-saugnieu.html

[1] https://calatrava.com/projects/lyon-saint-exupery-airport-railway-station-colombier-saugnieu.html

III. Lily Pad City

Lily pad project designed by Vincent Calleburt is a concept for a future city to provide shelter for future climate change refugees. It depends on a self-sufficient floating city which depends on the inspiration from the structure of highly ribbed leaf of the great lily pad of Amazonia Victoria Regia[1] (see fig. 3-13).

Figure 3-13 Lily pad, A Floating Ecopolis.
Source: http://vincent.callebaut.org

3.6.1.2 Forms of Structures in Nature:

In nature, Organisms build their shelters from the natural materials in the surrounding environment. These materials which organisms use could be either existing materials in the surrounding or the organism can produce it from his body such as spiders. Organism can produce a huge number of structures and shapes from these materials which could be categorized into a set of recurring forms and principles[2]. Some of forms of structures which organism built in natural world are declared as following (see fig. 3-14):

- Tension membrane structures – Leaf cutter ant nest, weaver ant nest, silkworms, spider webs
- Hemisphere/sphere – Potter wasp, ovenbird nest, cactus wren nest, spittlebug nest
- Parabolic Forms – Bowerbird nests
- Combined structural shapes and forms – Termite towers, prairie dog burrows
- Hemisphere/mound forms – Beaver dams, ant nests,
- Tube/cylinder forms – Swallow tailed swift nest, bagworm case, jaw fish, shark and the helix, brine shrimp nest.
- Egg/bell shapes – Africa gray tree frog, paper wasp and honeybee nest, weaverbird nest.

[1] http://vincent.callebaut.org
[2] Tsui, E. (1999), "Evolutionary architecture - nature as a basis for design".

Figure 3-14 Structures built by organism
Source: Neal P. (2006), "An Exploration into Biomimicry and its Application in Digital & Parametric [Architectural] Design". P: 38.

There are many buildings use forms of structures in nature. Some examples of this category will be discussed as follows:

I. Beijing National Stadium (Bird's Nest)

The building of national stadium in Beijing designed by ARUP is called also bird's nest according to the inspiration of its form. The form of the stadium was inspired from the shape of the bird's nest. Birds built their nests with a high-performance structure made from light members that guarantee both the stability and function of the nest. The floor area of the stadium is 254,600m2 with 91,000 seats including 11,000 temporary seats. The huge span of stadium structure is based on 24 trussed columns and weighing 1000 tons each and use steel members in different directions to form the outer shell[1] (see fig. 3-15).

[1] http://www.arup.com

Figure 3-15 Right-National Stadium (Bird's Nest) and left- the bird's nest form. Source: http://www.arup.com

II. Beijing National Swimming Center

National Swimming Center in Beijing designed by PTW architects John Bilmon is called also water cube because of the inspiration of water in its foam state. As the building is all about water, designers inspired its structure from the foamy state of water as it was magnified into the structure of the building in the form of a voronoi diagram. Water becomes a profound 'building material' that dematerializes the building in a meaningful way. Structure of the building is composed of large number of molecules of water foam which is attached to each other according to the voronoi mathematical function.

The structure of water softens and dissolves all the boundaries, and gives the sophisticated 'micro' details to the monolithic totality. An interesting duality of the building visualization arises from the sophistication of the components and the simplicity and monumentally of the whole building[1] (see fig. 3-16).

[1] Patrick X. W. et al. (2010), "Lessons Learned from Managing the Design of the Water Cube National Swimming Centre for the Beijing 2008 Olympic Games".P: 175-188.

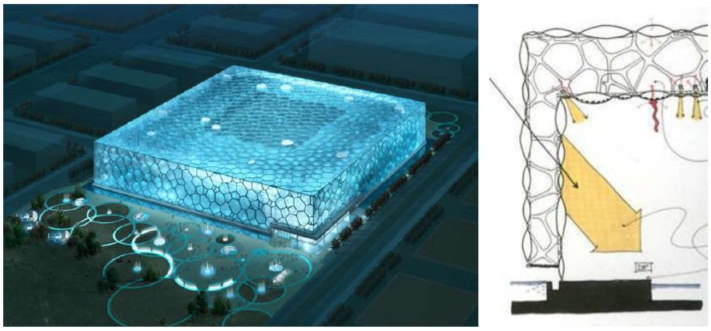

Figure 3-16 National Swimming Center in Beijing (water cube).
Source: Patrick X. W. Zou, Rob Leslie-Carter. (2010), "Lessons Learned from Managing the Design of the Water Cube National Swimming Centre for the Beijing 2008 Olympic Games".P: 175-188.

III. UAE Pavilion, Shanghai, China

In 2010 Shanghai Expo, UAE Pavilion was inspired from sand dunes found in the desert of UAE. It represents a symbolic reference with the desert landscape over which each of the seven emirates presides. Prevailing winds in desert could affect Sand dunes shape and smooth as it may have rough and smooth surfaces. Pavilion form mimics the duality of sand dunes surface according to the environmental impacts. Porous structure of the northern façade allows natural light to penetrate through it while the surface of the southern façade is closed and non-porous in order to reduce heat infiltration during the exhibit[1] (see fig. 3-17).

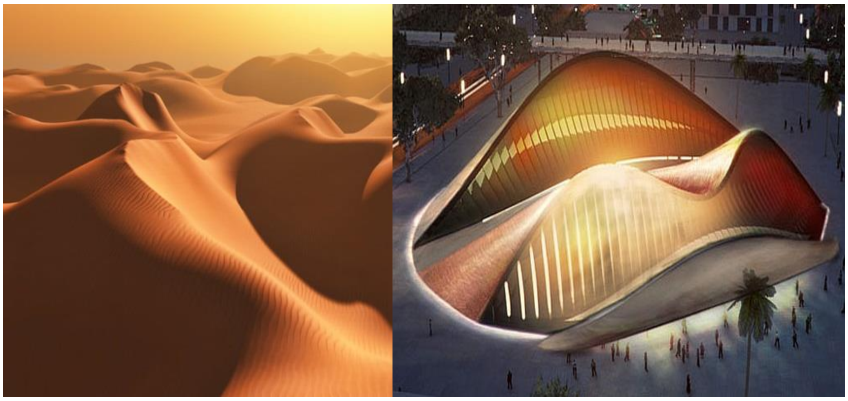

Figure 3-17 UAE Pavilion in Shanghai Expo 2010
Source:https://www.fosterandpartners.com/projects/uae-pavilion-shanghai-expo-2010/

[1] Vahid G. (2014), "Fabrication-Oriented Design; Assessment of Fabrication Parameters Affecting Design Process". P: 3.

3.6.1.3 Materials Owned by Natural Organisms:

The materials which organisms own have specific characteristics which enable the organisms to overcome the surrounding environment cases and circumstances. The characteristics of these materials could be considered as a fertile source for inspiration. There are many examples of environmental materials that depend on the inspiration from organism material characteristics such as[1],[2]:

- Responsive materials
- Self-cleaning materials
- Self-healing materials
- Phase change materials
- Color without paint materials

There are many buildings use materials owned by natural organisms in building envelope. Some examples of this category will be discussed as follows:

I. Buildings of Angila Ruskin University

The concept of making building skin respond and interact with the interior and exterior environments could be achieved by making building facades behave even more like natural skins. This concept used in building skins in Angila Ruskin University. Buildings skins are responding to regulate humidity, temperature, daylight and gas exchange. The common building skins form static barriers between indoor and outdoor environment. However, in information technology age with the help of new technology designers have the opportunity to design dynamic responsive building skins (see fig. 3-18).

Figure 3-18 Responsive Skin of A Building in Angila Ruskin University.
Source: John Y. (2011), "Biomimetic Building Skin: A Phenomenological Approach Using Tree Bark as Model". P: 3.

[1] KieranTimberlake (2011), "SmartWrap™: Building Envelope of the Future".
[2] http://www.pcmenergy.com

II. Self-Cleaning Enzyme Nanotube - Polymer Composite material

Many researches in the field of self-cleaning techniques have been worked on in order to employ Nano technology as a new technology with huge capabilities. One example of such projects is NSEC project (Dordick) which involves the formation of self-cleaning (and potentially self-healing) coatings. The project produced a new building material depends on enzyme attached to Nano tubes which could be carbon or other material. The enzyme is placed in a simple polymer (e.g., PMMA) and then this material acts as a coating or film endowed with bio-catalytic activities. If outdoor harmful objects such as bacterial cells are contacted to the building skin which uses the new building material, the coating will destroy it by the action of specific enzymes in the coating. This material may also prove useful as a coating to resist and destroy pathogens that come in contact with a surface coated with the bionano composite (e.g., textiles and fabrics, machinery, etc.) [1] (see fig. 3-19).

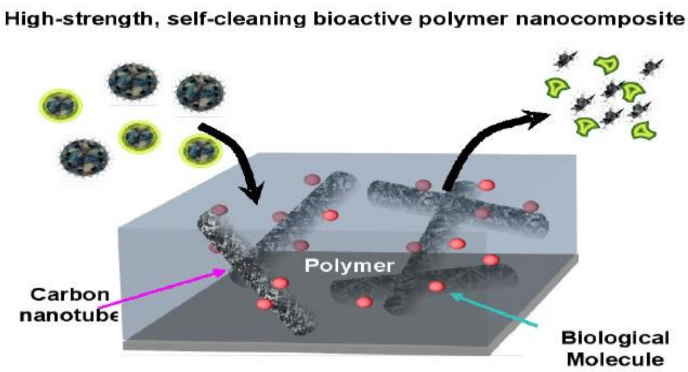

Figure 3-19 Self-Cleaning Enzyme Nanotube- Polymer Composite material. Source: https://www.rpi.edu/dept/nsec/02_01-highlights.html#104

III. Self-Cleaning Glass material

The concept of producing self-cleaning glass was inspired from the lotus flower which always has a clean surface. The researchers found that it have the ability to resist dirt due to its surface characteristics. A new coating material for glass was proposed by researches called nanocrystalline titanium dioxide (TiO_2). The new material has similar

[1] https://www.rpi.edu

characteristics of lotus flower and works in two stages. First stage called ‘photocatalytic’ stage as the titanium dioxide found in the composition of the new material reacts to the ultraviolet (UV) component of sunlight causing a gradual break down and loosening of dirt.

The second stage called hydrophilic stage as the reaction between titanium dioxide (TiO_2) and ultraviolet (UV) component also causes the glass surface to become super hydrophilic. The two stages force water to spread across the surface like a sheet, rather than beading, thereby washing away the loosened debris on the surface of the glass as it falls[1] (see fig. 3-20).

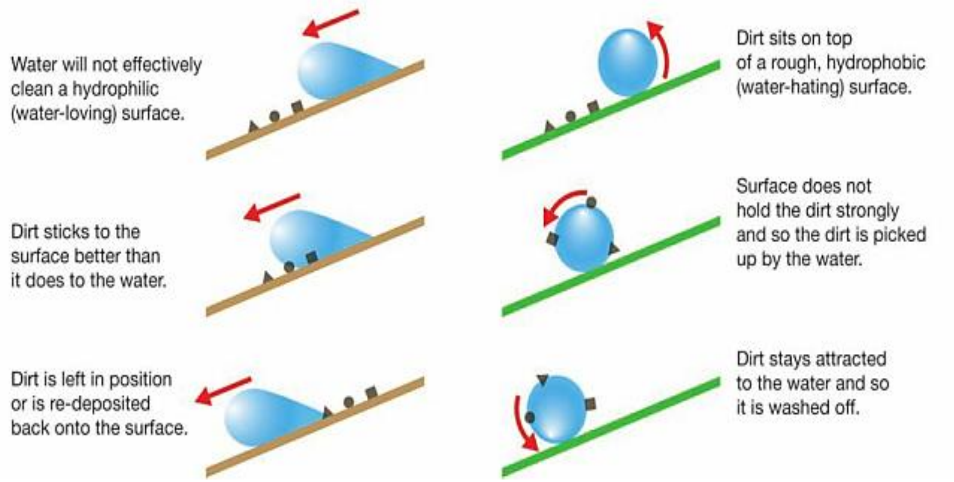

Figure 3-20 Self-Cleaning Glass material.
Source: https://infograph.venngage.com/p/40808/self-cleaning-glass

IV. <u>BacillaFilla material</u>

A new building material called BacillaFilla created by a team of Newcastle University (U.K.).the new material is helpful when it is added to concrete due to its healing capabilities without adding any other materials to concrete. BacillaFilla material depends on bacteria in its components as the research team developed a genetically modified microbe designed to reconstruct cracks that form in concrete.

[1] Nandang M. , Ifa K. R., Laila H. and Abdulloh F. (2017), “The effect of TiO_2 thin film thickness on self-cleaning glass properties”.

'This biological patch ultimately cures to the same strength as the surrounding material'[1] (see fig. 3-21).

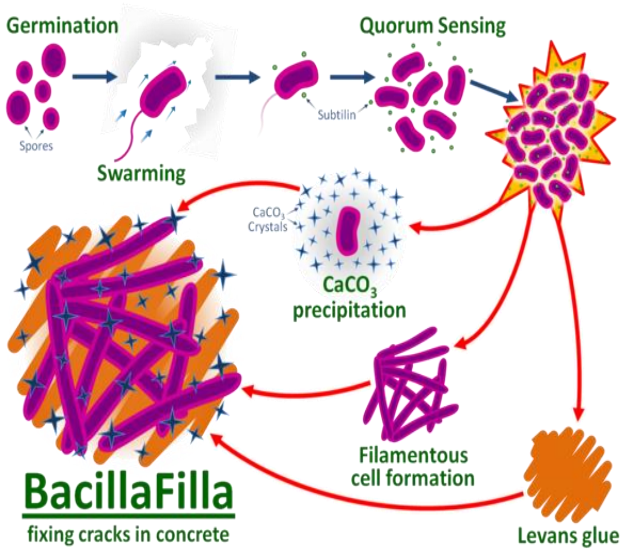

Figure 3-21 BacillaFilla material. Source:http://www.robaid.com/tech/bacillafilla-bacteria-can-repair-cracks-in-concrete.htm

V. Biological Concrete material

A research group in the Universitat Politècnica de Catalunya and BarcelonaTech (UPC), Spain, has presented a type of concrete inspired from the concept of biology. The main concept of the new material is a type of biological concrete that supports the natural, accelerated growth of pigmented organisms. The new material designed mainly for Mediterranean climates as it is adapted to provide thermal, environmental and aesthetic advantages more than any building material in this climate. Research field is focused on two materials have the same structural technology as the first material is a material manufactured with magnesium phosphate cement (MPC), while the other is a cement-based material – carbonated concrete (based on Portland cement). Carbonated concrete is a material with a pH of around 8, while the material combined with MPC does not require any treatment to reduce its pH, since it is slightly acidic[2] (see fig. 3-22).

[1] Brownell, B. (2011), "Self-Healing Concrete".
[2]http://www.robaid.com

Figure 3-22 Biological Concrete material. Source:https://www.urbangardensweb.com/2013/01/10/organic-concrete-for-living-green-facades/

VI. Glass X material

Recently, the need of materials that could respond and improve its environmental performance is increased. Phase Change Materials (PCMs) is one of these materials which are "latent" energy storage materials and can change its state to improve its environmental performance during the day. These PCM materials use chemical bonds to store and release heat. Generally, in materials, the energy transfers in phase change process or when a material changes from a solid to a liquid or from a liquid to a solid. This process called a change in state, or phase[1]. Glass X is a new product_which uses the ability of PCMs for energy transfer when phase change was developed. The glazing system by Green lite Glass Systems is developed in Switzerland. 'The Glass X glazing system incorporates a salt-hydrate phase change material that stores energy from the exterior temperature and reuses it to either heat or cool the building as needed, putting less pressure on the mechanical HVAC system'[2],[3] (see fig. 3-23).

[1] http://www.pcmenergy.com
[2] Orrell, R. C. (2010), "New Breed of Glazing Uses Salt Hydrate PCM". P: 55.
[3] Thomas F. V. (2015), "Future Energy Developments: Key To Our Green Future". P:3.

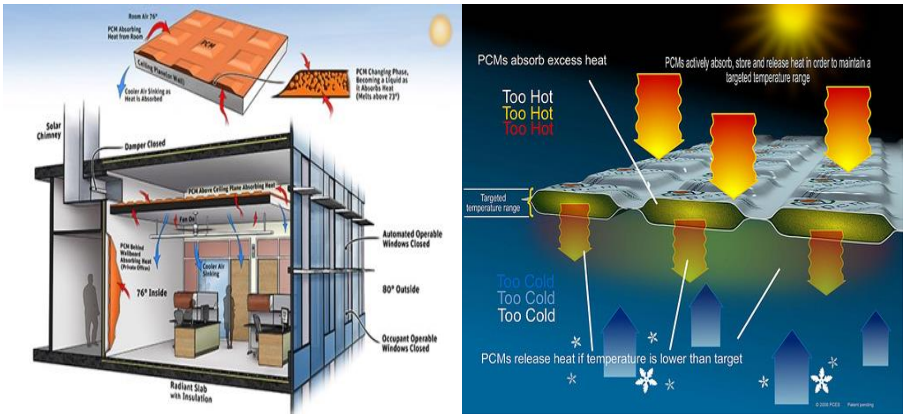

Figure 3-23 Phase change materials (PCMs).
Source: Thomas F. V. (2015), "Future Energy Developments: Key To Our Green Future". P:3.

3.7 Design Strategies Inspired From Nature

Benyus Declared that nature can affect architecture by many different ways and methods such as[1]:

- Materials as Systems – Nature builds from small to large with a corresponding scaling of function in relation to the materials and components involved for particular functions.
- Resilience and Healing – Living organisms have the ability to absorb and rebound from impacts and can repair themselves if damage is incurred.
- Solar Transformations – Many organisms respond actively to the sun to maximize their energy absorption.
- The Power of Shape – Nature uses many structurally efficient non-orthogonal forms with which to create its structures.
- Life creates conditions conducive to life – The waste products and various byproducts of growth and sustenance create materials that are beneficial to the growth of other organisms.
- Self-Assembly – The ability of an organism to direct its own process of development.
- Natural selection as an innovative engine – Environmental forces that act on an organism and affect its fitness will direct the development of future organisms.

[1] Benyus, J. (2004), "Biomimicry".

- Material Recycling – Create structures using materials that are non-toxic and can be fully recycled at the end of their life.
- Ecosystems that Grow Food – Systems are created that have a net surplus of production without a corresponding drawdown of environmental resources.
- Chemistry in Water – Nature produces all of its compounds in normal environmental conditions without a necessity for extreme temperatures or harsh chemicals.
- Energy savvy movement and transport – Locomotion and internal circulation systems have adapted to require a minimal investment of energy for their purpose.
- Sensing and Responding – A series of feedback systems within an organism allow it to sense a variety of environmental factors acting on it and to respond to these in a suitable manner.

3.8 Summary

Biophilia effect reflects the close relationship between human and environment. Environment attracts human in many ways and strategies. Whereas organisms in nature managed to survive in different tough environmental conditions by adapting their abilities and bodies to achieve environmental balance, so human formulated the biophilic design patterns which rely beyond natural strategies to use it in buildings in order to achieve balance in the indoor environment. Biophlic design patterns divided to three main categories nature in space, natural analogies and nature of the space.

The most important category is natural analogies which is the main concern of research. Natural analogies enable designers to use biomimicry strategies depending on successful preceding experience of organisms in nature for managing environmental control in indoor spaces. The next chapter will focus in biomimicry concept and strategies.

Biomimicry is the process of imitating natural organism strategy in order to benefit similar problem which it managed to solve it in natural life. Biomimicry is considered the most important and essential fertile source of inspiration for new innovative solutions for designers to overcome, control and enhance different environmental conditions. Biomimicry has two approaches to be used through their processes which are design looking to biology and biology influencing design. The application of biomimcry could be inspired from forms of natural organisms' composition, forms of structures in nature and materials owned by natural organisms. Each application of biomimicry is led by a biomimicry level which helps in formulating the whole process of biomimcry. Levels of biomimicry are categorized to three main levels organism level, behaviuor level and ecosystem level.

It is needed for performing a successful process of biomimcry to enhance thermal performance of building envelope to choose the suitable biomimicry approach, application and level as discussed. Depending on biomimicry inspiration, a digital model for building envelope design could help in controlling and examining the thermal performance of building envelope which is inspired from nature. How Digital model could be generated by using algorithms which formulate the biomimicry process and produce the desired model with required characteristics will be discussed in the following chapter.

3.9 Conclusion

Biomimicry, a well-known pattern of biophilic design, formulates a large pool of sources to be inspired by architects for solving many problems in built environment. According to natural organisms' strategies in natural environment, the inspiration from nature depends on two approaches, three levels and three biomimicry applications. Each approach, level, and application could provide the inspiration process by many solving variables. The study of biomimicry concept presents its capabilities to both control and solve environmental problems in buildings. The research concentrates on using biomimicry concept for solving the problem of thermal performance enhancement for building envelope (see fig. 3-24).

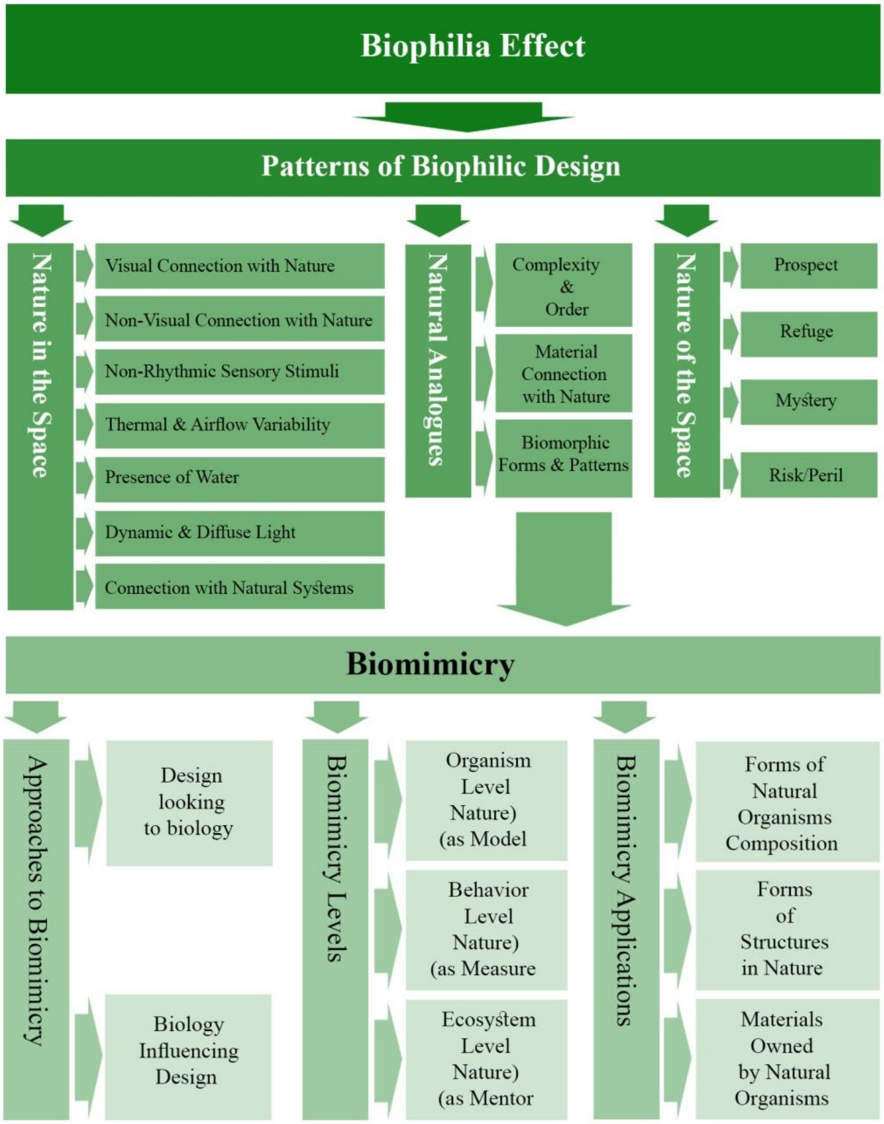

Figure 3-24 Chapter Three Conclusions
Source: Author

Chapter Four
Biomimetic Optimization Algorithms

Chapter Four
Contents

Biomimetic Optimization Algorithms

Chapter Four
Biomimetic Optimization Algorithms

4.1 Introduction

In this chapter, the research concentrates on the using of digital design in terms of algorithms in optimization process. In order to performing an optimization process architects need an inspiration source to follow and inspire its treatments to overcome the common environmental problems. Biomimetic optimization algorithms represent the correlation between the treatment of biomimicry from nature and algorithmic digital design. The classifications of biomimetic optimization algorithms are presented in this chapter to investigate its capabilities and characteristics through the analysis of its components and application in architecture.

4.2 Algorithms for Optimization

Algorithms are used in architecture as optimization tools to find the best solutions of natural problems. Designers use algorithms in formulating the relation between architectural forms and inspiration process from nature. In digital architecture, there are a large number of natural inspired algorithms which derived from both nature observations and treatments for organisms[1]. These new algorithms have very useful benefits as they can solve and describe very complex shapes and relationships from abstracting simple rules and conditions. Nature inspired algorithms could perform to provide designers by best conditions without or with little knowledge of searching area in the same condition as the real world's optimization problems are very challenging to solve[2]. Many types of new algorithms are used due to their accuracy and high efficiency in solving optimization problems such as firefly algorithm, cuckoo search and swarm optimization.
Obviously, it is a difficult challenge to classify the new types of nature optimization algorithms as there are no clear indicators to guide in this classification. The classification of nature inspired algorithms will

[1] Dennis D., (2005), “Toward Biomimetic Architecture”.
[2] Binitha S, S Siva Sathya, (2012), “A Survey of Bio inspired Optimization Algorithms”.

focus on one issue of its characteristics which is the source of inspiration from which it was formulated.

4.3 Inspiration Sources of Optimization Algorithms

Many researchers and designers are inspired by nature in different ways as nature provides a wide range field for inspiration. For digital architecture, most common used algorithms are nature-inspired algorithms because they were derived and developed from nature. Generally the main inspiration source is nature. The majority of new algorithms used in architecture could be referred to as nature-inspired or biomimetic optimization algorithms.

The best example of optimization is nature. If we check carefully every phenomenon or organism in nature, it will be cleared that it is always seek for the optimal solution and strategy. The selected strategy is flexible and changeable according to input conditions as organisms in nature still address the new complex relations to reach the balancing state for ecosystem which guarantees the diversity and adaptation of organisms. The nature is the great teacher, so an easy connection between nature and technology could be possible mapped as the problems in nature which encounter organisms have a lot in common with problems in computer science. Although the strategy behind best solution is simple, the results are complex, magnificent and not predictable[1].

4.4 Biomimetic Optimization Algorithms Classification

Methodologies for solving classical problems include two approaches which are exact methods (logical, mathematical programming) and Heuristics. The most common used and superior in solving complex and hard optimization problems is heuristic approach when traditional methodologies fail to solve problems. Biologically inspired algorithms are best examples of heuristic approach that mimic or imitate the strategy of nature since many biological processes can be thought of as processes of constrained optimization. Biologically inspired

[1] Iztok Fister Jr., Xin-She Yang, Iztok Fister, Janez Brest, Duˇsan Fister, (2013), "A Brief Review of Nature-Inspired Algorithms for Optimization". P. 1–7

algorithms are a special class of randomized algorithms as it mainly depends on random decisions. The formula for any designs which depend on biologically inspired algorithms should contains Sequential stages which are firstly choosing of the suitable problem representation, then evaluating the quality of solution using a fitness function and finally defining operators so as to produce a new set of solutions.

Many researches and studies were operated in the field of biomimetic optimization algorithms thanks to the success of its strategies and techniques in solving intricacy problems. The following taxonomy presents a classification of biomimetic optimization algorithms[1] (see fig. 4-1):

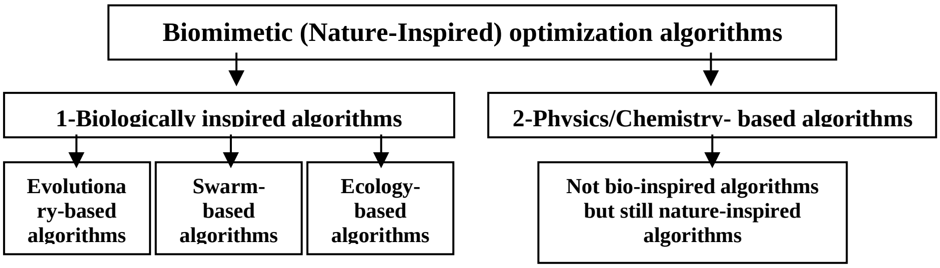

Figure 4-1 Taxonomy of Biomimetic Optimization Algorithms
Source: Binitha S, S Siva Sathya, (2012), "A Survey of Bio inspired Optimization Algorithms". P: 2.

4.4.1 Biologically Inspired Algorithms

The main first category of this classification is biologically inspired algorithms. It refers to all algorithms inspired from organisms in nature to solve certain problem in design. This category could be subdivided into three secondary classes which are algorithms; Evolutionary-based algorithms, Swarm-based algorithms, and Ecology-based algorithms.

4.4.1.1 Evolutionary-Based Algorithms

Among the Artificial intelligence paradigms, evolutionary computation is a famous paradigm that depends on the benefits comes from collective phenomena in adaptive populations of problem solvers

[1] Binitha S, S Siva Sathya, (2012), "A Survey of Bio inspired Optimization Algorithms". P:2.

utilizing the iterative progress comprising growth, development, reproduction, selection and survival as seen in a population. Evolutionary Based Algorithms are the Most commonly used of algorithms in this category as it depends on the biological evolution of all organisms in nature that includes both the adapting and interacting strategies of each organism. Evolutionary based algorithms are neither deterministic algorithms nor cost based optimization algorithms.

Evolutionary Based Algorithms include successful examples such as genetic programming, genetic algorithms, paddy field algorithm, differential evolution, and evolutionary strategy. Algorithms in this class are all population-based stochastic search algorithms performing with best-to-survive criteria. Generally, each algorithm in this class launches optimization process by creating an initial population of feasible solutions, and promotes reiteratively between all generations from generation to generation towards a best solution. Fitness-based selection takes place within the population of solutions in sequential repetition of algorithm. The best solution from any generation is chosen for survival into proposed solutions of next generation.

I. Genetic Algorithm

Genetic Algorithms could be considered from the best class of successful algorithms which are inspired from evolutionary approach from nature. Holland presented Genetic Algorithms in 1975 which are based on stochastic optimization algorithm with a global search potential[1]. The concept of Genetic Algorithms lies among the theory of Charles Darwin of survival of the fittest options. Genetic Algorithms have been dignified as function optimizers because of the distinguished performance in problem optimization. The working process of Genetic Algorithms consists of sequential steps. Firstly, algorithms build an initial population of possible solutions similar to chromosome in genetics; Then Genetic Algorithms evaluate the fitness each chromosome using an appropriate fitness function suitable for the problem. According to these process, the best and fittest chromosomes are selected into mating pool, where they afford cross over and variation thus giving new set of solutions (offspring)[2].

[1] Holland J.H., (1973), "Genetic algorithms and the optimal allocation of trials". P: 88–105.
[2] Hazem M. T. (2009), "Revisiting Algorithms in Architectural Design – Towards New Computational Methods". P :103-122.

II. Genetic Programming

The extension of Genetic Algorithms is Genetic Programming proposed by Koza in 1992[1]. Genetic Programming differs in terms of the solution's representation. Genetic Programming illustrates an indirect encoding of a possible solution (in the form of a tree), in which search is applied to the solution directly, and a solution could be a computer program. The second major difference for Genetic Programming is in the variable-length representation adopted by Genetic Programming in contrast with the fixed length encoding in Genetic Algorithms. The population in Genetic Programming generates diversity in both the values of the genes and the structure of the individuals.

III. Evolution Strategies

Bienert, Schwefel, Rechenberg, were three students at the Technical University in Berlin who developed Evolution Strategies in 1964[2]. The proposed strategies were in a potential to robotically optimize an aerodynamic design problem. Evolution Strategies are optimization algorithms inspired fundamentally from the theory of adaptation and evolution in terms of natural selection. The level which Evolution Strategies are inspired is different from the level which Genetic Algorithms are inspired. Evolution Strategies are inspired by macro-level or the species-level process of evolution (phenotype, hereditary, variation) while genetic algorithm which deals with micro or genomic level (genome, chromosomes, genes, alleles). The utilization of self-adaptive mechanisms for controlling the application of variation could be considered the most important characteristic of Evolution Strategies. These Strategies are aimed at optimizing the progress of the search by evolving both the solutions for the problem being considered, and some parameters for variation of these solutions.

[1] Koza, John R. (1992), “Genetic Programming: On the Programming of Computers by Means of Natural Selection”.

[2] Beyer, H.G. and Schwefel, H.P. (2002), “Evolution strategies”. P: 3–52.

IV. Differential Evolution

Storn and Price proposed Differential Evolution as one of Evolutionary Based Algorithms paradigms in 1995[1]. The main concept of Differential Evolution is similar to Genetic Algorithms as it depends on the idea of using populations of individuals to search for an optimal solution. Nevertheless, the main difference between Differential Evolution and Genetic Algorithms is that, in Differential Evolution variation and mutation is the result of arithmetic combinations of individuals while in Genetic Algorithms variation and mutation is the result of small disturbance to the genes of an individual. At the initial phase of the evolution process, the variation and mutation operator of Differential Evolution supports reconnaissance. Going through the evolution process the operator supports exploitation. Hence, Differential Evolution automatically adapts the mutation excesses to the best value based on the stage of the evolutionary process. Mutation in Differential Evolution is therefore not based on a predefined probability density function.

v. Paddy Field Algorithm

Premaratne et al. proposed Paddy Field Algorithm in 2009[2], which depends on a reproductive standard dependent on proximity to the global solution and population density similar to plant populations. Paddy Field Algorithm differs from Evolutionary algorithms as it uses pollination and dispersal while evolutionary algorithms use either crossover or combined behavior between individuals in population.

A. Example 1: Hybrid house (using crossover)

The design of hybrid house begins by designing five building units using CAD application then exported these buildings into Maya application. Then, by using scripting language such as MEL language designers write a program in order to perform Genetic Algorithm. The

[1] Storn R., Price K.. (1997), “Differential evolution – a simple and efficient heuristic for global optimization over continuous spaces”. P:341–359.

[2] Upeka P. , Jagath S., and Tarlochan S. (2009), “A New Biologically Inspired Optimization Algorithm”.

result of Genetic Algorithm was 3125 offspring in the first generation by an exhaustive combination of five original units' genotype[1].

During the execution of Genetic Algorithm, Designers add more deformations on building units as they add three nonlinear deformation nodes which are wave, twist and bend. The three nodes were evolved independently in the evolution and then explicitly added to the five units to yield a more complex layout potential. As the result of adding these nodes in the third generation, high level of complexity of results were generated through generations. In this phase of design, the variation of results provides genetic algorithm with great power and unlimited potential of form reproduction driven from sets of genetic parameters. Then designers select the preferable spatial layouts that survived and reproduced them to create the new generation. During generation process and exactly in the fourth generation, designers add a central courtyard to the evolution as a "void unit" and blended with the selected layout. Time, as the 4th dimension, was also added to control all layout possibilities through motion (see fig. 4-2).

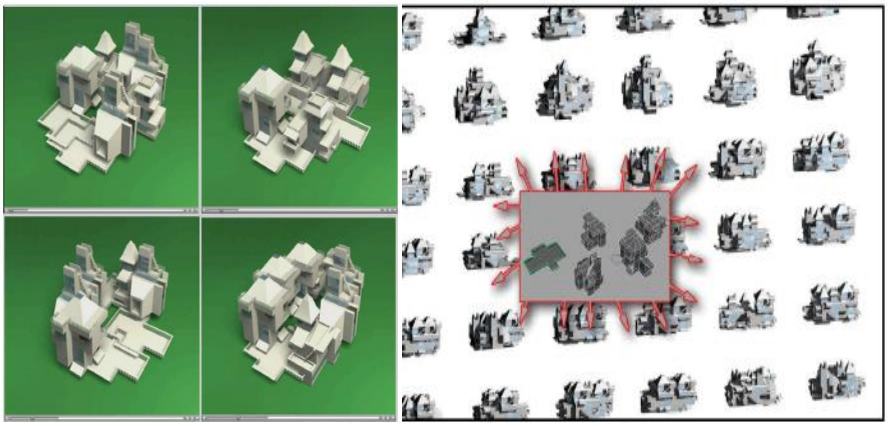

Figure 4-2 Hybrid House generated by Genetic Algorithms - The animation was captured from 3125 spatial arrangement solutions crossed four generations. Source: Hazem M. T. (2009), "Revisiting Algorithms in Architectureal Design – Towards New Computational Methods". P :114.

4.4.1.2 Swarm-based algorithms

From many paradigms presented in bio inspired computing, Swarm Intelligence is a recent and emerging paradigm for implementing

[1] Frazer, J., Frazer, J., Liu, XY., Tang, MX. and Janssen, P. (2002), "Generative and Evolutionary Techniques for Building Envelope Design".

adaptive systems. Swarm intelligence is different from Genetic Algorithms as Swarm Intelligence depends on collective social behavior of organisms while Genetic Algorithms depend on adaptation of organisms[1]. Evolutionary based algorithms have been developed alongside with Swarm Intelligence. The concept behind Swarm Intelligence involves the implementation of collective intelligence of groups of simple agents that are based on the behavior of real-world insect swarms, as a problem-solving tool. The word ―swarm derived from the irregular practice of the particles in the problem space. Swarm Intelligence algorithms are inspired from many sources such as exhibit decentralized, the collective behavior of animals and self-organized patterns in the foraging process. There are many algorithms derived from Swarm Intelligence such as Particle Swarm Optimization, Ant Colony Optimization and Artificial Bee Colony Algorithm[2].

I. <u>Particle Swarm Optimization</u>

In 1995, Kennedy and Eberhart presented Particle Swarm Optimization which is a computational intelligence oriented, stochastic, population-based global optimization technique[3]. The concept of this optimization algorithm is inspired from the social behavior of bird flocking searching for food. Particle Swarm Optimization has various characteristics such as simple concept, unique searching mechanism, easy implementation, and computational efficiency. Thanks to these characteristics Particle Swarm Optimization has been widely applied for many problem optimizations in engineering field.

II. <u>Ant Colony Optimization</u>

In 1999, Dorigo & Di Caro proposed one of the most successful swarm-based algorithms, which is Ant Colony Optimization[4]. It is inspired from the foraging behavior of ants in the wild as a meta-heuristic algorithm. The concept lies behind the ability of collaborative behavior of several ant species to find the shortest paths between the ants' nest and the food sources by

[1] Hazem M. T. (2009), “Revisiting Algorithms in Architectural Design – Towards New Computational Methods”. P :97-102.
[2] Bonabeau, E., Dorigo, M. and Theraulaz, G.(1999), “Swarm intelligence”.
[3] Kennedy, J.; Eberhart, R. (1995), "Particle Swarm Optimization".P: 1942–1948.
[4] Dorigo, M., Maniezzo, V., & Colorni, A. (1996), “Ant System: Optimization by a colony of cooperating agents”. P: 29–41.

tracing pheromone trails Then, ants choose the path to follow by a probabilistic decision biased by the amount of pheromone: the stronger the pheromone trail, the higher its desirability.

III. <u>Artificial Bee Colony Algorithm</u>

Karaboga and Basturk proposed a swarm intelligence algorithm depends on the inspiration of bees' behavior in nature[1]. The proposed algorithms could be categorized into two classes; mating behavior and foraging behavior. Artificial Bee Colony is a prevailing algorithm simulating the intelligent foraging behavior of a honeybee swarm. Employed bees, onlookers and scouts are three groups of bees that have been included in Artificial Bee Colony Algorithm just like in the real world of bees' kingdom.

A. <u>Example 1: UK pavilion, Shanghai Expo 2010</u>

The pavilion form is a box with dimension of 15 meters high and 10 meters tall. It is also called Seed Cathedral. There are 250,000 seeds cast into the glassy tips of all the hairs[2]. From every surface emerge silvery hairs, consisting of 60,000 identical rods of clear acrylic, 7.5 meters long, which extend through the walls of the box and lift it into the air. By using Swarm Intelligence, the geometry of rods forms an interior space of pavilion described by a curvaceous undulating surface[3] (see fig. 4-3).

Figure 4-3 UK pavilion, Shanghai Expo 2010
Source: https://www.arch2o.com/uk-pavilion-for-shanghai-world-expo-2010-heatherwick-studio/

[1] D. Karaboga, B. Basturk, (2007), "A powerful and efficient algorithm for numerical function optimization: artificial bee colony (ABC) algorithm". P: 459–471.
[2] http://www.heatherwick.com
[3] https://www.arch2o.com/uk-pavilion-for-shanghai-world-expo-2010-heatherwick-studio/

B. Example 2: Shade Sclupture by Arne Quinze

Arne Quinze is famous for his trademark sculptures made out of wooden planks. The shade sculpture designed by Arne Quinze is a large frame structure that depends on colors, lines, curves and movement in the composition. Structure of the shade reflects the feeling of fluidity and movement. Quinze sees his installations as places where people meet each other again and start social communications[1]. Forms and compositions designed by Arne Quinze are built to affect passengers' feelings on any public pedestrian such as encouraging reaction and interfering in the daily life of passersby who faced with his sculptures[2] (see fig. 4-4).

Figure 4-4 Shade Sclupture by Arne Quinze
Source: https://www.arnequinze.com/art-and-exhibitions/cityscape

4.4.1.3 Ecology-based algorithms

One of the most efficient sources for inspiration is natural ecosystem. In nature ecosystems, there are various mechanisms and strategies could be inspired in order to solve hard problems in engineering and computer science fields. Ecosystems in nature involve both living organisms and the biotic environment which organisms interact such as soil; water and air etc. for any ecosystem, there are plentiful types of interaction between the living species.

The interaction in natural ecosystems has two types as it can either be interspecies interaction which occurs between species or intra species interaction which occurs within species. Inter species interaction can

[1] http://www.workbydjg.com
[2] https://www.arnequinze.com/art-and-exhibitions/cityscape

be divided into three types based on the outcome of interaction (positive, negative, neutral) termed as mutualism, parasitism, commensalism respectively. The nature of these natural ecosystems' interactions could be cooperative/ competitive. As per Cooperation interaction, the interaction includes division of labor and represents the core of sociality. Among the Cooperation interaction in nature there is many examples such as between species (i.e., heterogeneous cooperation, also called symbiosis), within species (i.e., homogeneous cooperation, also called social evolution), as in the social foraging behaviors of animal herds, bird flocks, insect groups and bacterial colonies and as in the mutualism between human and honey guide[1].

There are many applications of biomimetic algorithms depend on the concept of ecology-based strategies such as Invasive Weed Colony Optimization, PS20 and Biogeography- Based Optimization.

I. Invasive Weed Colony Optimization

Mehrabian and Lucas presented Invasive Weed Optimization as a numerical stochastic search algorithm in 2006[2]. It was inspired from the ecological process of weed colonization and distribution. It is a powerful algorithm which has the ability to solve general multi-dimensional, linear and nonlinear optimization problems with appreciable efficiency. Invasive weeds usually adapt to their environment circumstances so it cover spaces of opportunity left behind by improper tillage then it follow this covering by enduring occupation of the field. Because of invasive weeds behavior, there is lesser opportunity of life for the ones with lesser fitness as the colony becomes denser.

II. PS20

Hanning Chen and Yunlong Zhu presented PS20 as a biomimetic optimization algorithm application in 2008[3]. It was inspired from the concept of the coevolution of symbiotic

[1] Binitha S, S Siva Sathya, (2012), "A Survey of Bio inspired Optimization Algorithms".
[2] Mehrabian A.R., Lucas C., (2006), "A novel numerical optimization algorithm inspired from weed colonization". P: 355–366.
[3] Hanning C., Yunlong Z. (2008), "Optimization based on symbiotic multi-species coevolution".

species in natural ecosystems and heterogeneous interaction between species. Simply, PS20 is a multi-species optimizer that extends the dynamics of the canonical PSO algorithm by adding a significant ingredient that takes into account the symbiotic co evolution between species.

III. Biogeography- Based Optimization

Dan Simon proposed Biogeography-Based Optimization as a global optimization algorithm in 2008[1]. The proposed algorithm was inspired from mathematical models of biogeography by Robert MacArthur and Edward Wilson. Biogeography is mainly focus on the study of distribution of species in nature over time and space; that is the immigration and emigration of species between habitats. The concept of this algorithm is to authorize information sharing between solutions proposed by different candidates.

4.4.2 Physics/Chemistry- Based Algorithms

The second main category of biomimetic optimization algorithms encompasses strategies which are not biologically -inspired but still nature-inspired as many algorithms. Such algorithms could be developed by using the inspiration from physical, chemical systems and may be music[2].

Because of the source of inspiration for optimization may come from chemical or physical characteristics, not all met-heuristic algorithms are bio-inspired algorithms. Inspiration from chemical or physical characteristics could be performed by mimicking certain physical and/or chemical laws, including gravity, electrical charges, river systems, etc[3]. This category includes a wide range of natural inspired algorithms. The relationship of physics and chemistry-based algorithms could be presented as the following equation (see fig. 4-5):

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[1] Simon, D., (2008), “Biogeography-based optimization”. P: 702–713.
[2] Zong W. G., et al. (2001), “A new heuristic optimization algorithm: harmony search”. P: 60–68.
[3] Iztok F. Jr., Xin-She Y., Iztok F., Janez B., Duˇsan F. (2013), “A Brief Review of Nature-Inspired Algorithms for Optimization”. P: 1–7.

$$\frac{\text{Physics algorithms}}{\text{Chemistry algorithms}} \begin{cases} \notin \text{bio-inspired algorithms} \\ \in \text{nature-inspired algorithms} \end{cases}$$

Figure 4-5 The Relationship of Physics and Chemistry Based Algorithms
Source: Zong W. G., et al. (2001), "A new heuristic optimization algorithm: harmony search". P: 62.

Although chemistry and physics are two different branches, it is not useful to separate it into secondary subcategories such as chemistry-based algorithms and physics-based algorithms. So it is generally grouped into one group named physics and chemistry based algorithms. Many types of algorithms were presented in the last few years which depend on physical and chemical characteristics such as the following (see tab. 4-1):

I. <u>Stochastic Diffusion Search</u>

Generally, a stochastic search algorithm could be defined as a random search in space until a given condition is reached[1]. Stochastic search used in optimization for the application of Stochastic Diffusion Search which is optimization algorithms. The concept of stochastic diffusion search depends on incorporating probabilistic elements (in random way), either in the algorithm itself through random parameter choices, values, etc., or in the problem given data through the constraints, the objective function, etc., or in both issues[2].

The concept of stochastic search could be explained by understanding the ant behavior when it seeks to find food. When taking into consideration an example of the nature life such as hypothetical ant-like creatures searching for a good nutrient source in a dynamic environment. The normal state for ants is that each ant requests and searches for locating some food and returns it back to the ants' nest. The colony as a whole seeks to increase the rate of return food amounts otherwise to decrease the disbursement of energy. Each ant seeks for food daily without any helping information for food location so each searching ant leaves the nest and executes a random walk around the nest location. When any ant finds some food or food

[1] Terzidis, K. (2006), "Algorithmic Architecture".
[2] Spall, J. C. (2003), "Introduction to Stochastic Search and Optimization".

source during the exploration process, then it returns to the nest as a positive ant; otherwise, it is labeled negative[1].

Table 4-1 Physics and Chemistry Based Algorithms
rce: Zong W. G., et al. (2001), "A new heuristic optimization algorithm: harmony search". P: 64.

physics and chemistry based algorithms	Proposed by
Big Bang-big Crunch	Zandi et al.
Black Hole	Hatamlou
Central Force Optimization	Formato
Charged System Search	Kaveh and Talatahari
Electro-Magnetism	Cuevas et al.
Galaxy-Based Search	Shah-Hosseini
Gravitational Search	Rashedi et al.
Harmony Search	Geem et al.
Intelligent Water Drop	Shah-Hosseini
Simulated Annealing	Kirkpatrick et al.
Stochastic Difusion Search	Bishop

A. Example1: Accumulata : organizing a certain façade for office building based on stochastic search. By Gyoscope

Stochastic diffusion Search as optimization algorithm was used in this project to provide different generations of impressive facades. The proposed composition resulted from using a certain unit which was a box with changing in scale and dimensions. The boxes alter in its location, scale, distribution and overlap between each other in the façade design according to predefined rules by designers[2] (see fig. 4-6).

[1] Bishop J.M., Nasuto S.N., (1999), "Communicating Neurons - an Alternative Connectionism".
[2] Terzidis K. (2006), "Algorithmic Architecture". P:127

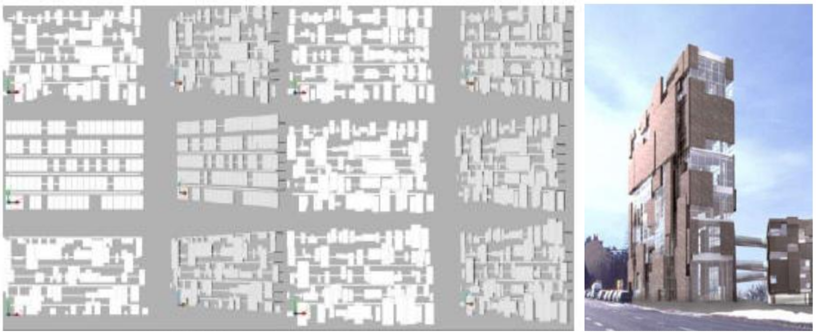

Figure 4-6 Office Building Façade Based On Stochastic Search And Various Iterations For The Façade.
Source: Terzidis K. (2006), "Algorithmic Architecture". P:127

B. <u>Example 2: Library: generated by the research group of Harvard Graduate School of Design.</u>

Stochastic diffusion Search as optimization algorithm was used in this project to generate the architectural design of the library. Every space in the library space program is represented by a box which has been distributed according to predefined architectural rules in order to guarantee the fulfillment of all function needs in library spaces. Each box has a dimension of 30*30 unit in a square shape. Stochastic diffusion Search algorithm performs an XY coordinate system that generates a square range to adjust all available positions for the program units. The architectural programs of a library could be fulfilled by accumulating a certain number of such modular units, each of them has its uniqueness in X and Y values as a spatial entity and its Z value is determined by the connectivity between each other. The algorithm produces a large number of generations which meet both the functional and the architectural need (see fig. 4-7).

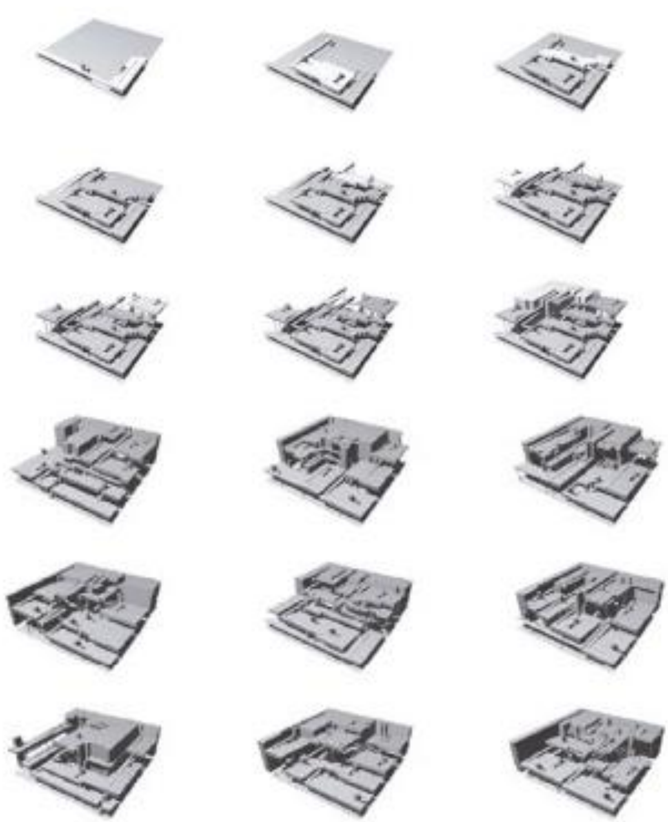

Figure 4-7 Generation of Library Design Using Stochastic Diffusion Search Algorithm Source: Hazem M. T. (2009), "Revisiting Algorithms in Architectural Design – Towards New Computational Methods". P :79

4.5 Summary

In digital information age, algorithms were used in digital design due to its ability for generating, controlling and changing the final product easily. An infinite number of generations could be produced by a single and simple algorithm formation which supplies designers with enormous number of complicated concepts and ideas. Designers by themselves and their own abilities cannot imagine and predict the results of performing algorithm according to the complicated mathematical equations and process so algorithms open a massive source for new and innovative concepts and ideas for designers.

Algorithms is used not only to produce a digital model to any desired concept but also it is used to choose and identify the optimum solution for the input data and conditions which designers select to solve. Concepts and ideas which laterally are modeled by using algorithms could be inspired from nature by using biomimicry. The correlation between using algorithms for optimization and biomimicry for inspiration called biomimetic optimization algorithms. There are various number of successful biomimetic optimization algorithms. Biomimetic (nature-inspired) optimization algorithms could be divided to two main categories. The first main group is biologically inspired algorithms which depend on the inspiration of organism and this category is divided to evolutionary based algorithms, swarm based algorithms and ecology based algorithms. The second main category is Physics/Chemistry- based algorithms which are not biologically inspired algorithms but still nature-inspired algorithms.

The theoretical study focused on understanding thermal performance regulations in building and nature, beside the use of biomimicry and optimization algorithms as well in one process called biomimetic optimization algorithm. The next analytical study will focus on the inspiration of desired concept from nature and how to use algorithms to produce a biomimetic optimization model to control thermal performance of proposed building envelope then how to carry out thermal simulations analysis for enhancing the resulted performance of the proposed building envelope to achieve the thermal comfort rates.

4.6 Conclusion

As Algorithms present high capabilities in solving complex mathematical problems, the use of it in the integration process with biomimicry formulates a successful treatment for solving environmental problems. The development of using the integration between algorithms and biomimicry provides architects with the optimization concept for solving environmental problems in building. Many powerful biomimetic optimization algorithms are clear evidences and witnesses for this success. Biomimetic optimization algorithms help in producing a large number of optimal solutions for the assigned problems related to the assigned variables, mathematical functions and inspiration sources. The research concentrates on using genetic algorithms in enhancing thermal performance of building envelope (see fig. 4-8).

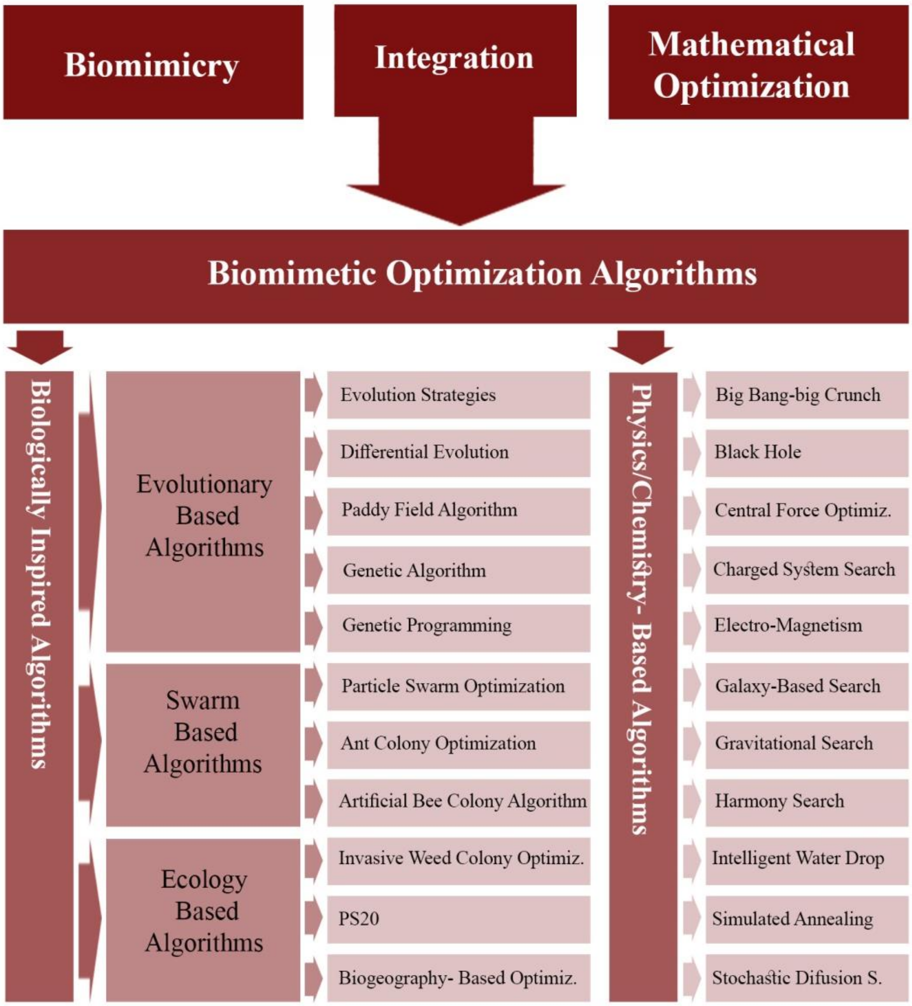

Figure 4-8 Chapter Four Conclusions
Source: Author.

Chapter Five
Optimization Process

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5.1 Introduction

In this chapter a proposed case study is investigated in order to examine how building envelope can enhance thermal performance of buildings using optimization process derived by biomimetic algorithms. A simple building geometry is chosen as the case study model. The proposed building is an office building. The proposed building is located in one of the selected case study cities. The proposed office building is a midrise building consists of five floors. The area of the proposed building is 378.00 square meters with dimensions equal 21.00*18.00 meters with total height equals 18.00 meters (see fig. 5-1). The main entrance is located in the south or west facade of the building according to the selected case study properties which is covered by curtain wall glazing system.

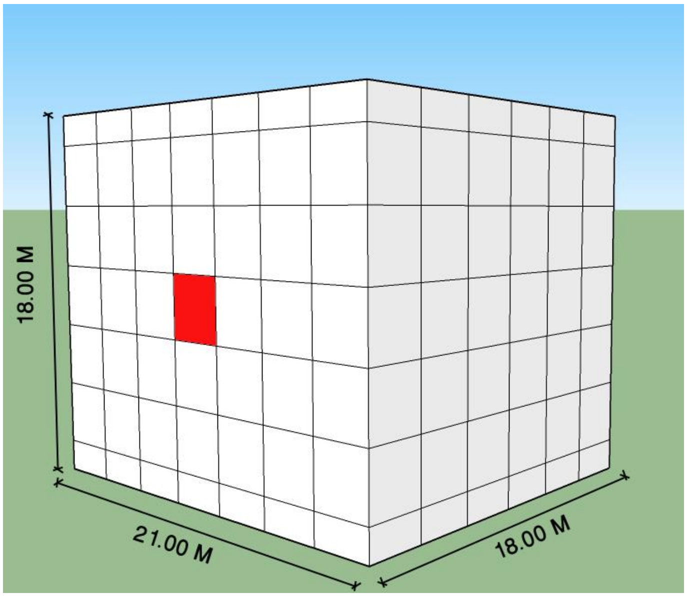


Figure 5-1 Geometry of The Proposed Office Building
Source: Author.

The proposed building envelope consists of multiple units of office rooms. The chosen unit to perform energy simulation on is located in the southern or western facade of the building. Particularly, it is located vertically in the middle of the building envelope in the third floor and horizontally in the middle of the building envelope. The chosen unit dimensions are 3.00 meters in length, 3.00 meters in width and the clear height of its architectural space is 3.00 meters. Its south façade is totally covered by curtain wall glazing system while the rest of its interior facades are brick walls. To simplify the problem, placement of the doors and the interior partition are not considered in the optimization process. According to research methodology the study will proceeds by the following steps.

5.2 Optimization Framework

The proposed design methodology is performed in an early stage of schematic design phase in building design process. According to design requirements and spatial needs of buildings, architects formulate the early design of buildings then perform the optimization process to have the optimum design for building which satisfy the assigned requirements and needs. For this research, it is oriented to optimize the thermal performance building envelope. For the optimization process of thermal performance, the optimization framework includes many ingredients such as Optimization Concept, optimization methodology, independent design variables, dependent design variables, optimization limitations, parametric platform and simulation engine.

5.2.1 Optimization Concept

The optimization process needs to be oriented through the different steps to have suitable optimum solutions for the subjected assumptions of proposed design. The concept of optimization process depends on three main pillars which are explained as follows (see fig. 5-2):

5.2.1.1 Thermal Performance

According to environmental effects of building envelope on Building sustainability, the proposed design of building envelope concept depends on using design variables of building envelope which affect thermal performance. The large number of varieties of building envelope design variables enables optimization process to achieve the optimal solutions for enhancing thermal performance of building envelope.

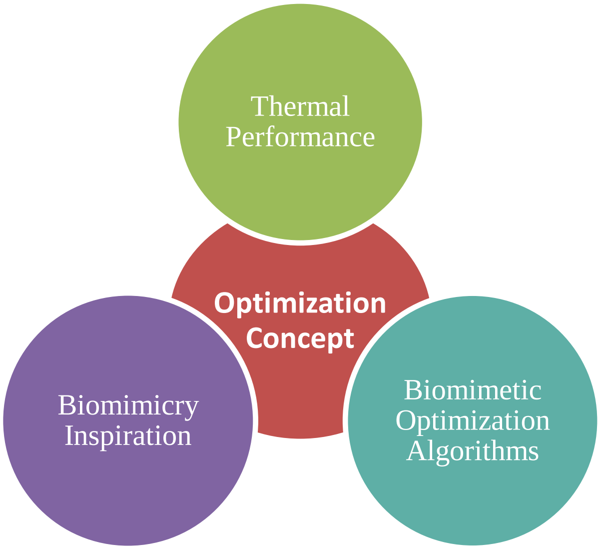


Figure 5-2 Optimization Concept Components
Source: Author.

5.2.1.2 Biomimicry Inspiration

The proposed design of building envelope concept depends on using one of biophilic design patterns which is biomimcry from the main category of natural analogues. The design of building envelope will follow the design looking to biology approach to inspire solutions from living organism which managed to overcome and enhance thermal performance of its body by using the shape of its skin. Also, the design of building envelope is following organism level as nature here in this situation is a model for optimal solutions. According to biomimicry application types which discussed previously in the research, the design of the proposed building envelope which enhances thermal performance will be inspired from the forms of natural organisms' compositions which are inspired from of living organisms.

The research concentrates on using (Ferocactus wislizenii) as an inspiration source for formulating the biomimicry concept of proposed building envelope design. In nature, barrel cacti plant has many spines formulating a self-shading device. These spines enable direct sun light. Barrel cacti plant has many ribs which could be described as a self-shading technique for it[1] (see fig. 5-3).

Figure 5-3 Barrel Cacti Plant
Source: Aysu K. a. (2018),” Multi-Functional Biomimetic Adaptive Façades: A Case Study”. P: 241-250.

According to a study of barrel cacti by using tiles made of aluminum (6061) sheets with octahedral surface articulations in building envelope. The surface area is covered by triangle shaped tiles each tile size is 4″ x 4″. A heat lamp was placed in order to enable the entire surface to receive heat radiation. The experiment concluded that while outer surface of building envelope with aluminum prisms will gain higher temperature, the internal surface of building envelope will gain lower temperature. When the building envelope is a smooth surface

[1] Novoa A. et al. (2014), “Introduced and invasive cactus species: a global review”. P: 02.

against the source of light the internal temperature will increase[1] (see fig. 5-4).

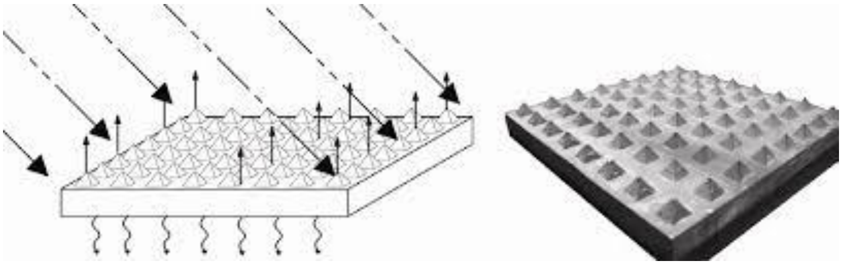


Figure 5-4 Aluminium (6061) Tile With Octahedral Surface Articulations. Source: J. Laver, et al. (2008), "High performance masonry wall systems: principles derived from natural analogues". P: 245.

As a result of large shaded area of barrel cacti outer envelope, the absorbed shortwave solar radiation resulting in a slower warming period throughout the day is minimized[2]. Also, the convective heat transfer rate is minimized as a result of self-shading surface areas caused by ribs and spines of barrel cacti. An isolating air layer could be generated on the surface of barrel cacti because of the depth of its ribs minimizes the wind speed. The folded shape and shaded surfaces of barrel cacti benefit in reducing thermal transfer and shortwave solar irradiation absorption[3].

According to the self-shading of barrel cacti shape the exposed surface to sun and heat radiation will has more temperature than the covered surface area by self-shading[4]. Therefore, the tangent air layer to the exposed surface area will gain heat more quickly than the non-exposed surface areas.

As the regulation of air movement to force hot air layers to move higher and be replaced by cooler air layers, an air current produced a self-ventilating effect in the surface of barrel cacti which helps in cooling its surface temperature. The folded surface of barrel cacti are used to create a micro-climate area under the shaded surface areas and

[1] J. Laver, et al. (2008), "High performance masonry wall systems: principles derived from natural analogues". P: 244.

[2] Aysu K. a. (2018)," Multi-Functional Biomimetic Adaptive Façades: A Case Study". P: 241-250.

[3] J. Laver, et al. (2008), Ibid. P: 246.

[4] Jens P.,(2011), "Building Science: Concepts and Application".

could help in reflecting direct and indirect solar radiation and this action keeps the rates of heat gain as minimum as it possible[1] (see fig. 5-5,6,7).

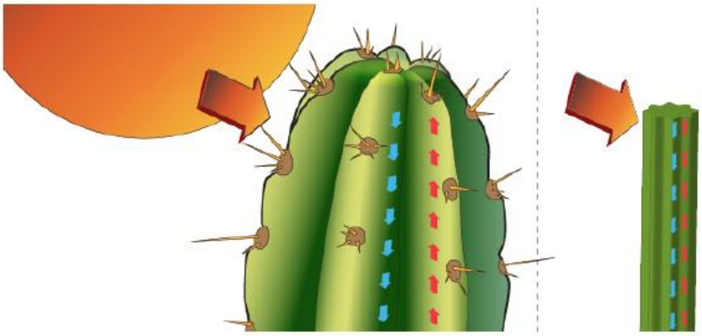


Figure 5-5 The Effect of Self-shading in Cooling Barrel Cacti surface.
Source: Parisa N. (2014), "Inspiration By Nature: Biomimicry Research Informs Adaptable Building Skin System For Natural Ventilation And Daylight In Hot Dry Climate". P: 12.

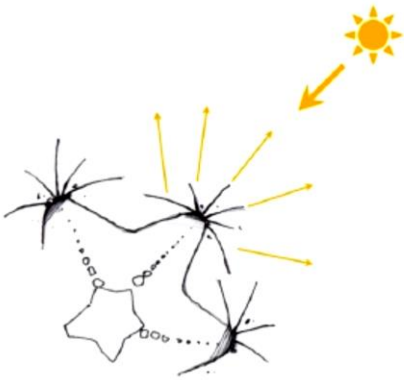


Figure 5-6 Spines of Barrel Cacti work as shade devices and help in cooling the surface by reflecting direct solar radiation.
Source: Parisa N. (2014), "Inspiration By Nature: Biomimicry Research Informs Adaptable Building Skin System For Natural Ventilation And Daylight In Hot Dry Climate". P: 12.

[1] Parisa N. (2014), "Inspiration By Nature: Biomimicry Research Informs Adaptable Building Skin System For Natural Ventilation And Daylight In Hot Dry Climate". P: 10-14.

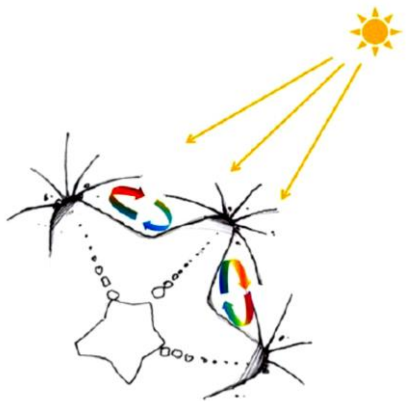


Figure 5-7 Micro-Climate Regions in Barrel Cacti surface Caused by Spines Source: Parisa N. (2014), "Inspiration By Nature: Biomimicry Research Informs Adaptable Building Skin System For Natural Ventilation And Daylight In Hot Dry Climate". P: 14.

5.2.1.3 Biomimetic Optimization Algorithms

The proposed design of building envelope concept depends on using biologically inspired algorithms for the optimization process. According to the classification of biomimicry optimization algorithms which is previously discussed, the optimal solutions for building envelope to enhance thermal performance will be generated by evolutionary based algorithms especially genetic algorithms.

Optimization concept depends on three main ingredients with emerging sub categories as follows (see fig. 5-8):

- First ingredient with sub categories: Building envelope – effects of building envelope on sustainability of buildings – environmental effect – achieving thermal comfort – thermal performance of building envelope – factors affecting thermal performance of buildings.
- Second ingredient with sub categories: Biophilia effect – patterns of biophilic design – natural analogues – biomorphic forms and patterns – biomimicry – design looking to biology approach – organism level – forms of natural organisms' composition.
- Third ingredient with sub categories: biomimicry integration with mathematical optimization – biomimetic optimization algorithms – biologically inspiration algorithms - evolutionary based algorithms – genetic algorithms.

5.2.2 Methodology

Using biomimetic optimization algorithms for enhancing thermal performance of building envelope could be achieved by applying a design methodology based on seven steps framework (see fig. 5-9).

The first step is to construct parametric model for the proposed unit of the building to be investigated and analyzed by using algorithmic design platform. The second step is to define model materials according to the thermal standards and weather in building location by using materials suitable for energy simulation engine. The third step is to design building envelope lattice which will be examined to achieve the optimum enhancement of thermal performance for the building.

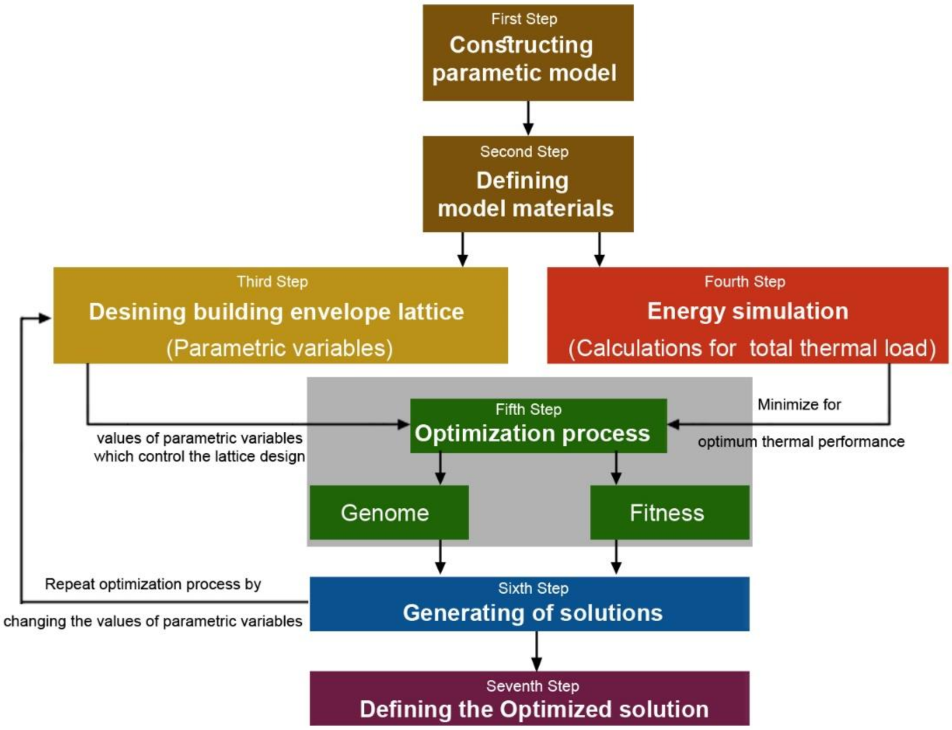


Figure 5-9 A Proposed Optimization Methodology
Source: Author.

The fourth step is to perform energy simulation according to the assigned weather conditions of building locations, materials and defined zones for analysis. The fifth step is to perform optimization process using biomimetic algorithms such as genetic algorithms to reach the optimum solution conditions for building envelope design which could achieve the optimum enhancement of thermal performance. The six step is to repeat the fifth step but with different inputs for building envelope design and calculate the related total thermal load to reach the optimum solutions. The seventh and final step is to extract results from the optimized solutions and choose the suitable solution for both building envelope visualization and enhancing thermal performance.

5.2.3 Independent Design Variables

For the parametric modeling of case study, there are many independent design variables of building envelope which will affect thermal performance of building envelope. Independent design variables are office room length, width, height, ratio of glazing window to wall in all façades, enclosure angle of lattice units, angle of rotation of each unit in envelope lattice, number of lattice unit, dimensions of each unit in building envelope lattice, and the distribution of lattice units in building envelope surface.

5.2.4 Dependent Design Variables

According to the optimization process, the dependent design variables represented by energy simulation output includes total thermal loads, cooling loads, heating loads, lighting thermal loads, and equipment loads.

5.2.5 Optimization limitations

The optimization process of case study has many limitations in order to facilitate the optimization process and concentrate on the research objectives. The research concentrates on two independent variables which are both enclosure angle and angle of rotations of building envelope lattice units. The case study in parametric model is defined by its dimensions which are fixed during the whole optimization process. The ratio of glazing to wall in east and west and north facades is zero as theses facades has no windows. The ratio of glazing to wall in southern façade or western – depending on the case study orientation- is fixed at 90 % to facilitate the optimization process and energy simulation. The selection of southern and western façades to put a large glazing to wall ratio in it maximizes the thermal loads in the assigned case study so the optimization process to enhance and minimize the resulted thermal loads is preferable and desired to control this thermal performance by building envelope.

The research assumes that the lattice units of building envelope have normal distribution in all the covered area of building envelope. The dimensions of lattice units are connected to glazing to wall ratio in south facades and its number is fixed to 10 units for each column and 10 units for each row.

On the other hand, the research concentrates on one dependent variable which is the total thermal loads of the assigned case study. Total thermal loads include heating, cooling, and lighting thermal loads of the case study. Thermal loads of equipment, color of building envelope lattice and material of lattice units are fixed values from the beginning of optimization process and its effects will be neglected.

The selection of case study cities depends on the variation of location around the world to test the validation of thermal performance enhancement according to the variation in values of building envelope digital design parameters. So, case study cities are chosen to be located in Africa, Europe, Asia, and North America.

5.2.6 Parametric Platform

Model of the proposed design of building envelope is built in parametric platform in order to control all parameters of design. For parametric modeling, Rhinoceros 3D and Grasshopper applications are used which are powerful applications in 3d model, form generation, and optimization functions. The Research uses Galapagos component in Grasshopper Plugin for optimization process as it is one of the most well-known optimization components.

In optimization process performed by Galapagos component, there are two types of input data. The first input represents genome which indicate to design variables in grasshopper plugin which defined by the proposed design variables which are in this case both enclosure angle and angle of rotation of building envelope lattice units. The second input represents the fitness function which defined in this case by total thermal loads calculated by simulation engine during the optimization process. The fitness function needs to be adjusted to minimize the total thermal load related to the resulted design generations.

5.2.7 Energy Simulation

In the modeling phase of proposed parametric model for building envelope, all input data for energy performance are assigned to its related item of the parametric model. Energy performance data include construction type, building materials, geometry adjacency, climatic zone, occupancy and operations in the space. For the optimization process, Ladybug and Honeybee plugins are used as simulation engines for optimization process. Both Ladybug and Honeybee plugins are performed by Grasshopper application. Ladybug plugin helps in performing the main function of modeling and define the weather conditions by generating a defined file for energy simulation. After simulation process Ladybug plugin call back the results of optimization process in grasshopper application and represent the energy results. Honeybee plugin helps in performing simulation process and visualizing climatic data.

Optimization process needs a simulation engine to perform all energy simulation functions on design variables. EnergyPlus is used as a simulation engine in this case. According to the input data gathered from design variables, climatic conditions and optimization fitness functions EnergyPlus calculates the total thermal loads resulted by building envelope for each generation during the optimization process. As the fitness function of the optimization process is adjusted to minimize thermal values, the optimal solutions will be the solutions with lowest thermal loads values calculated by EnergyPlus engine.

5.3 Parametric Modeling

The optimization process begins by constructing a parametric model of the proposed building envelope design. The model represented by variables and parameters which control all geometric characteristics and properties of design items. Modeling process is explained as follows:

5.3.1 First Step: Constructing Parametric Model

To model this building for parametric design a parametric model platform is needed, so the chosen unit of the building is modeled in Rhinoceros and Grasshopper application with the help of Ladybug and honeybee applications. The main idea of modeling is to disassemble the geometry of chosen unit to its basic parameters such as points, lines and surfaces to be easily controlled and tested. The chosen model unit created by the following code in Grasshopper application:

I. Create a box defined by two points which represent the chosen unit in the building envelope. The coordinates of these two points form previously proposed unit dimensions as it is represented in Rhinoceros is (00,00,00) for point 01 and (03,03,03) for point 02 (see fig. 5-10).

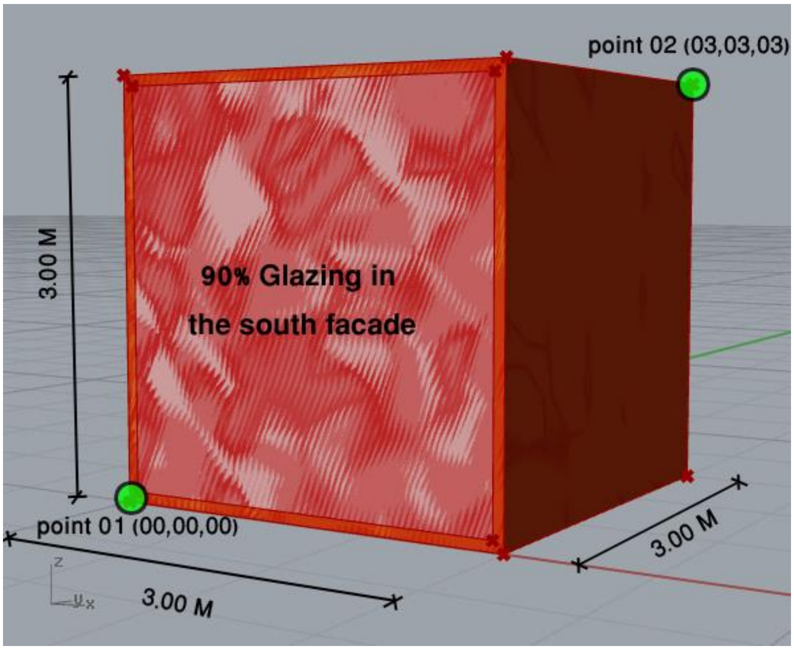


Figure 5-10 A Parametric Model For The Chosen Unit
Source: Author.

II. Convert the previously constructed box to brep component.

III. Define zones for honeybee application by plugging in the previously constructed brep into honeybee mass zone, then defining the zone program type by using the component of honeybee list zone programs for this building to assign its function which is proposed as office building. This component produces honeybee zones that have all of the properties necessary for an energy simulation assigned to them.

IV. Plug in the honeybee zones to honeybee glazing based on ration component which is a python scriptable component. This component enables designers to create glazing façade based on assigned ratio. For the proposed unit, curtain wall glazing system in south facade covered 90% from it and other facades are interior walls so they do not have outdoor glazing ratio. This component creates honeybee objects with assigned glazing necessary to an energy simulation (see fig. 5-11).

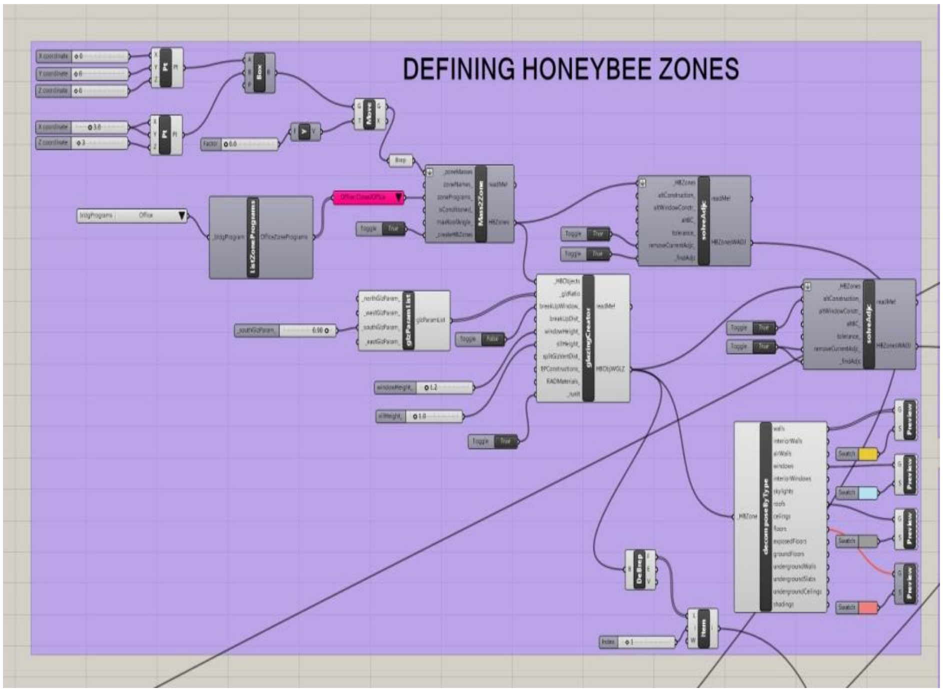


Figure 5-11 Grasshopper Preview Of Parametric Functions For Defining Honeybee Zones
Source: Author.

5.3.2 Second Step: Defining Model Materials

The next step after having honeybee objects with assigned glazing is to define the material of each surface of these objects as it has different thermal properties which will influence on the energy simulation of the whole model. The proposed materials are assigned under the following code (see fig. 5-12):

I. Plug in the honeybee zones which created by honeybee mass zones component to honeybee set EP zone construction component to define the thermal properties for each material according to the code of EnergyPlus engine.

II. Choose the proposed properties for each surface of the chosen model according to ASHRAE 90.1-2010 (Pacific Northwest National Laboratory, 2016) energy modeling standard by using honeybee search EP construction component (see tab. 5-1).

III. The proposed EnergyPlus material properties are assigned by using honeybee call from EP construction library component. The following table gives the assigned values of materials:

Table 5-1. Thermal Values For The Proposed Unit Materials
Source: Author.

Material	Interior Wall	Window	Ceiling	Floor
U-Value _SI (of the construction in W/m2-k)	3.690821	5.84	0.204317	0.20035
U-Value_IP (of the construction in Btu/h·ft2·°F)	0.64999	1.028482	0.035982	0.035284
R-Value _SI (of the construction in m2-k/W)	0.270942	0.171233	4.894354	4.991273
R-Value_IP (of the construction in h·ft2·°F/ Btu)	1.538484	0.972306	27.791458	28.341794

Note that this U-Value does not include the resistance of air film on either side of the construction and this resistance is typically included in U-Values used by manufacturers.

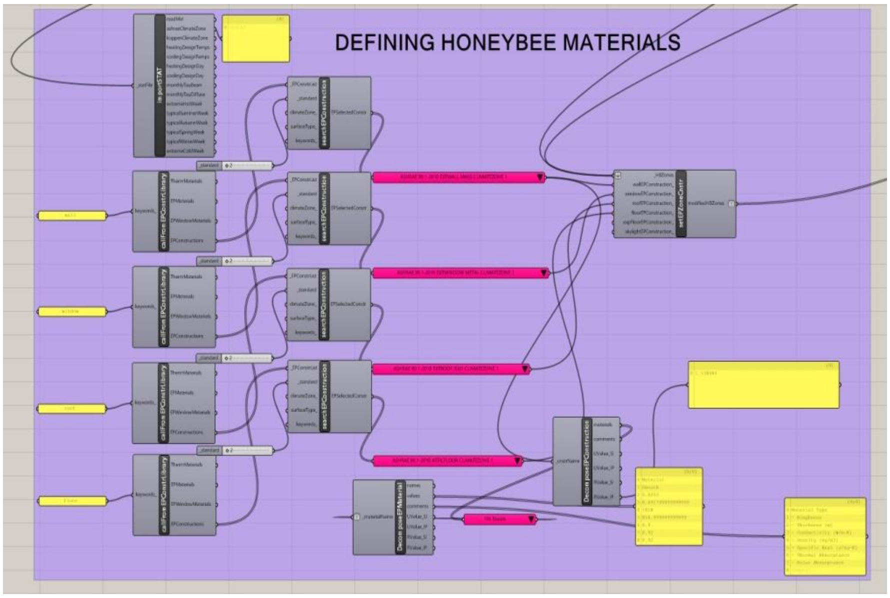


Figure 5-12 Grasshopper Preview Of Parametric Functions For Defining Honeybee Materials
Source: Author.

5.3.3 Third Step: Designing Building Envelope

The proposed building envelope consists of two components curtain wall glazing system and a lattice in front of it from outside the envelope. The size of the lattice is connected to the assigned ratio of the created glazing façade in model design process. The design of building envelope lattice is performed according to the following code (see fig. 5-13,14):

I. The main idea of the lattice depends on dividing the glazing façade into small equal 10 segments in both horizontal and vertical directions.

II. For each square, a point in the middle of each segment of the square is defined.

III. Connect each point with the following one by a line, so this produces a square shape rotated by 45 degrees.

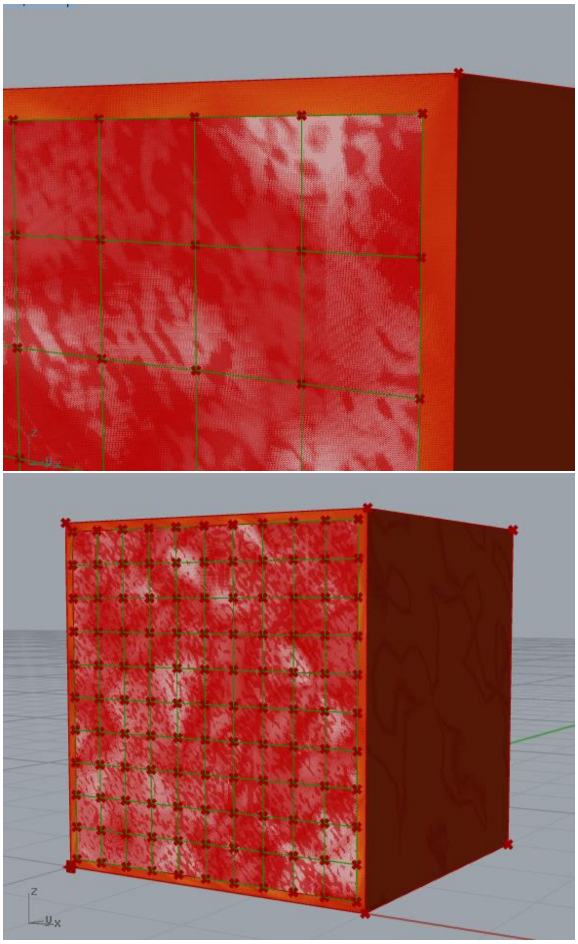


Figure 5-13 A Parametric Model For Building Envelope Lattice
Source: Author.

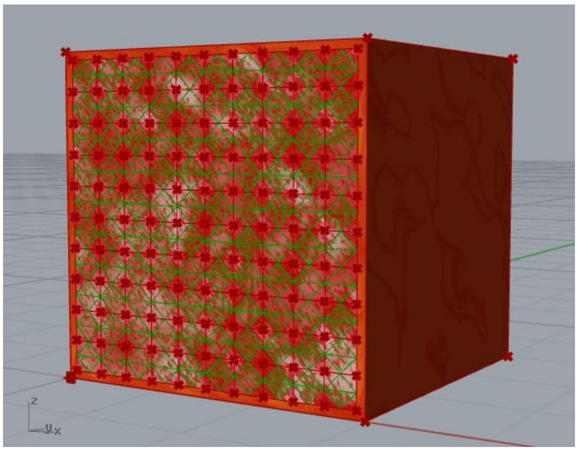


Figure 5-14 Square Units For Parametric Model For Building Envelope LatticeSource: Author.

I. Divide the resulted shape horizontally by a line to have two equal triangles. Assign a rotate function to enable each triangle to rotate by an enclosure angle towards each other based on the vertical line which divided the square as a rotation axis (see fig. 5-15).

II. Define a circle with a center located in the middle of rectangle diagonal and diameter equals to diagonal's length (see fig. 5-16).

III. Assign a rotate function to the two resulted triangles to rotate inside the parameter of the defined circle.

IV. Extrude the resulted triangles with the proposed thickness of the lattice to have a 3d geometry of each triangle (see fig. 5-17,18).

V. Define 3d geometry of the triangles as a brep component.

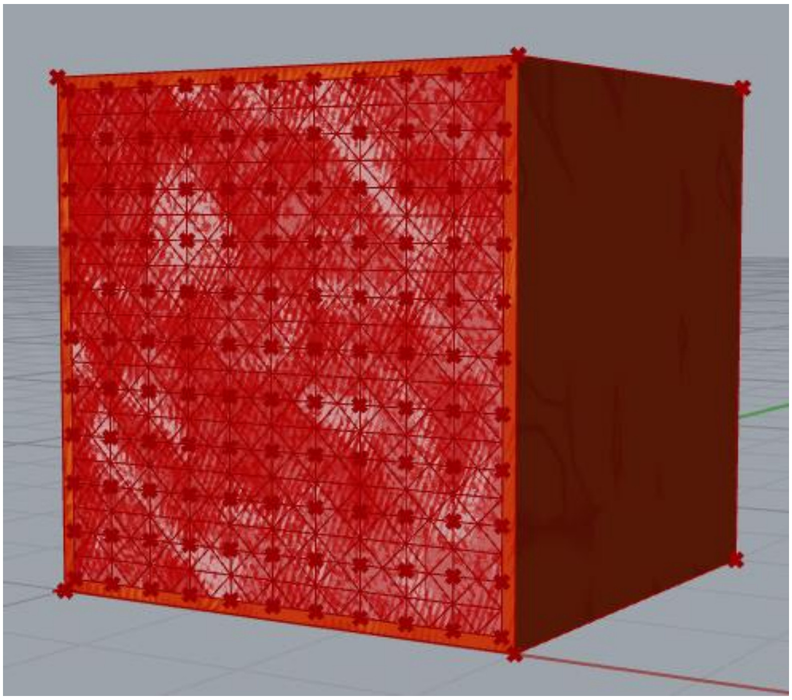


Figure 5-15 Divided Units For Parametric Model for Building Envelope Lattice
Source: Author.

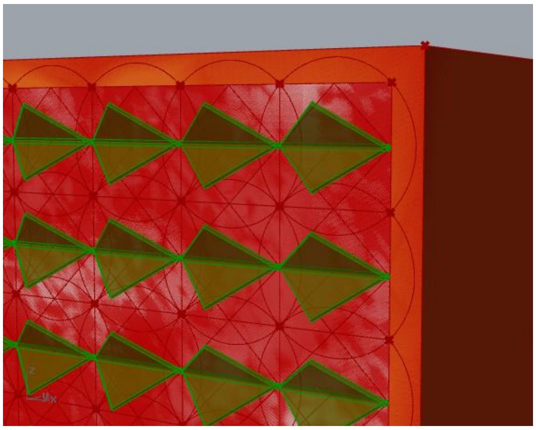


Figure 5-16 A Parametric Model for Horizontal Units of building envelope
Source: Author.

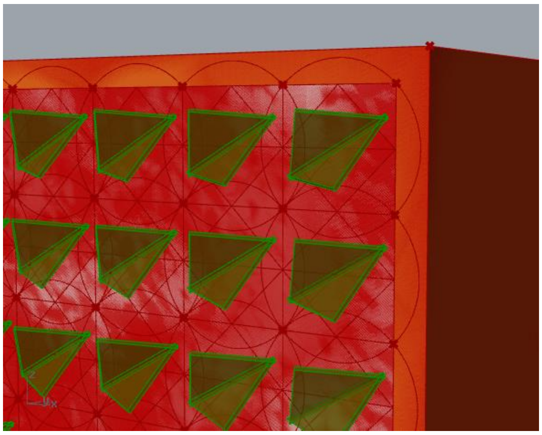


Figure 5-17 A Parametric Model for Rotated Units of building envelope
Source: Author.

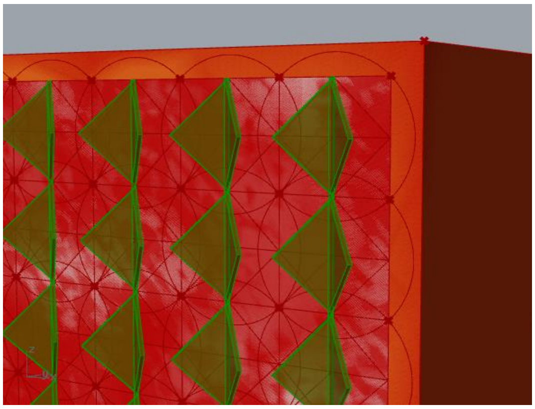


Figure 5-18 A Parametric Model for Vertical Units of building envelope
Source: Author.

VI. Define zones for honeybee application by plugging in the previously constructed brep component into honeybee mass zone component.

VII. Plug in the resulted honeybee zones to honeybee solve adjacencies component to have a list of honeybee zones with adjacencies solved (see fig. 5-19).

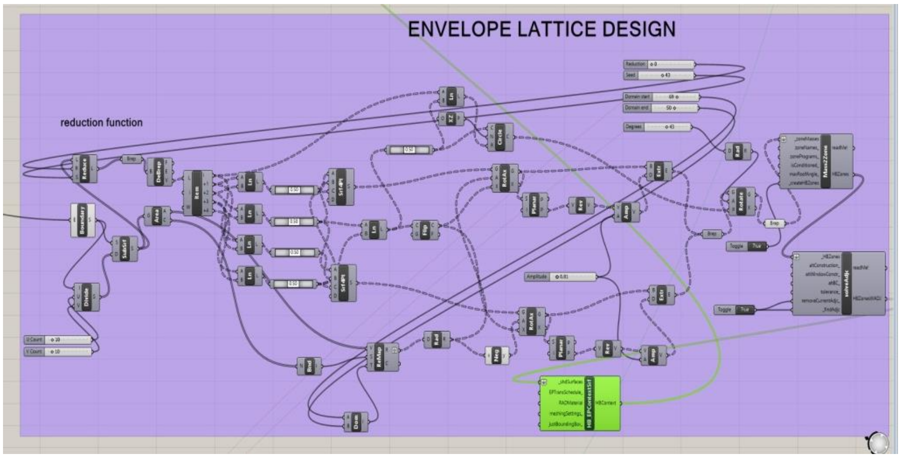


Figure 5-19 Grasshopper Preview Of Parametric Functions For Building Envelope Lattice Design
Source: Author.

5.4 Energy Simulation Process

To perform a successful energy performance using EnrgyPlus engine as proposed there are main components need to be defined from the initial phase.

5.4.1 Fourth Step: Performing Energy Simulation

Energy simulation is performed by the following code:

I. Define weather conditions of the proposed site which the office building is located. This step needs to download EPW weather file for selected city as a case study by using Ladybug _download EPW weather file component and open it by using Ladybug open and stat weather file component (see fig. 5-20,21).

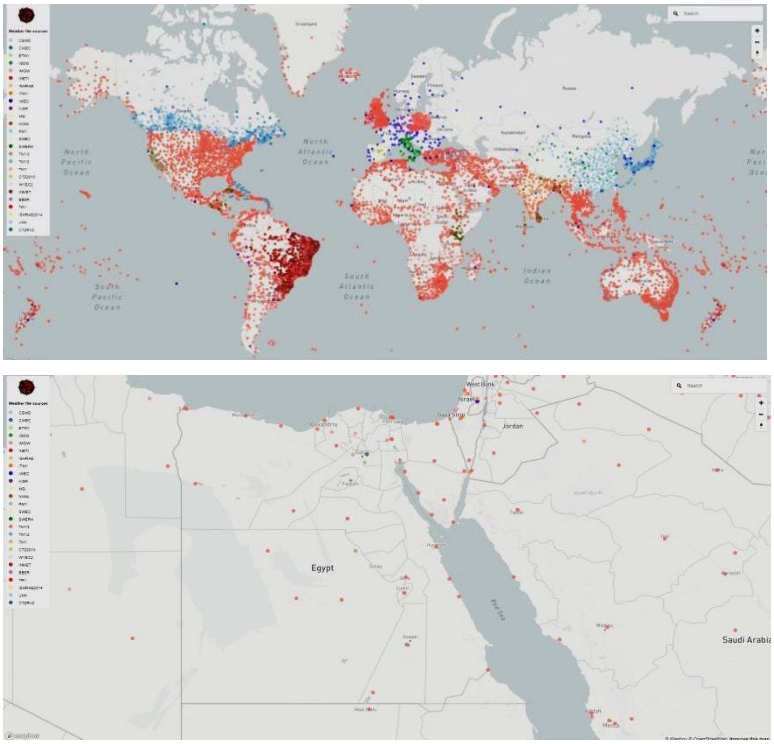


Figure 5-20 Locations of Free Download Epw Files for Weather Conditions In The World And Especially In EGYPT
Source: https://www.ladybug.tools/epwmap/

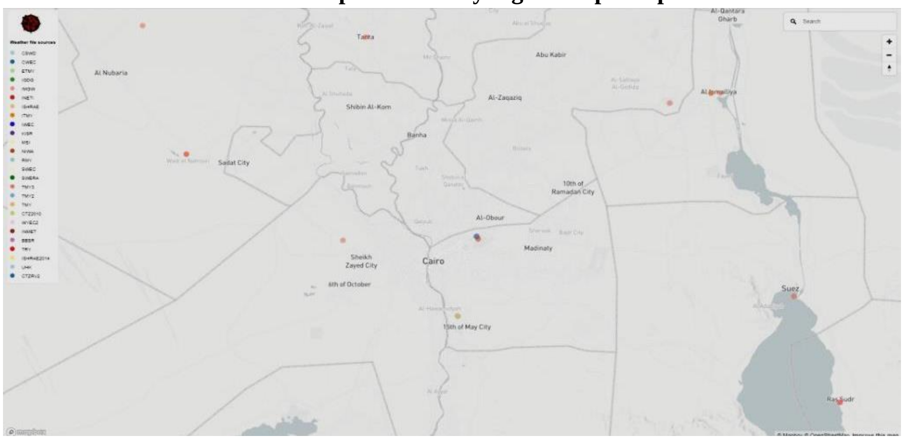


Figure 5-21 Locations of Free Download Epw Files for Weather Conditions In Shiekh Zayed City.
Source: https://www.ladybug.tools/epwmap/

II. Plug in the resulted EPW file to honeybee run energy simulation component which exports honeybee zones into an IDF file and run them through EnergyPlus and produce results reports (see fig. 5-22).

III. Plug in the previously assigned honeybee set EP zone construction for the model of office unit to honeybee zones input in honeybee run energy simulation component.

IV. Plug in the previously assigned honeybee zones with adjacencies solved list for the building envelope lattice to honeybee context input in honeybee run energy simulation component.

V. Defining analysis period of the simulation by using ladybug analysis period component and set the analysis from 1 to 30 Jul then plug in the resulted period to analysis period input in honeybee run energy simulation component.

VI. Defining the desired types of output from energy simulation by using honeybee generate EP output and plug the result in simulation output input in in honeybee run energy simulation component.

VII. Plug in honeybee read EP result to read file address output in honeybee run energy simulation component to preview all result calculations. The desired value is the total thermal load of the defined zones of the office unit.

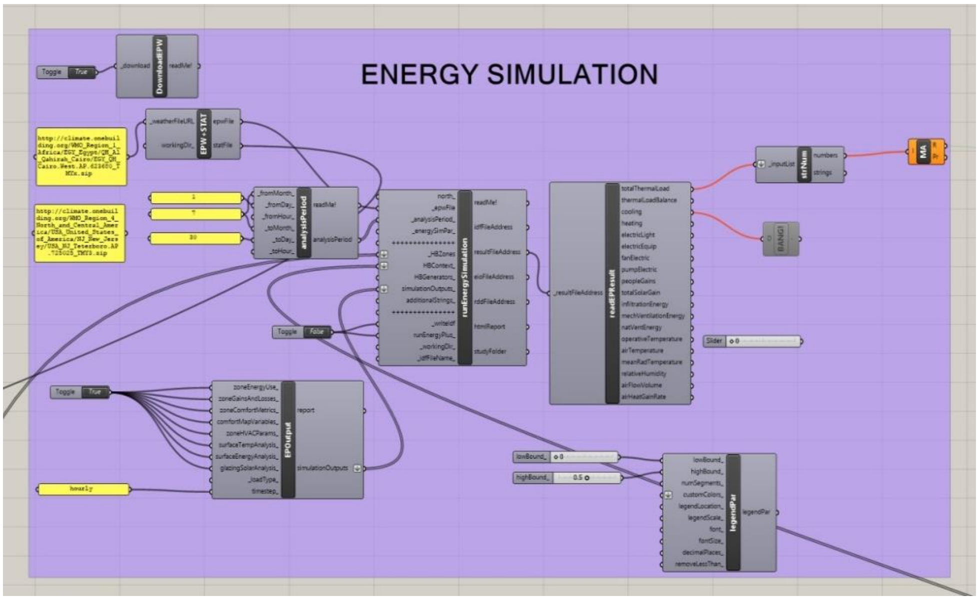


Figure 5-22 Grasshopper Preview Of Parametric Functions For Energy Simulation
Source: Author.

5.5 Optimization

The main core of optimization process depends on Galapagos as genetic algorithm optimization package derived by Grasshopper plugin (Labib, 2015).

5.5.1 Fifth Step: Optimization Rules

The optimization seeks to achieve the best thermal performance by reaching the minimum total thermal loads in July for the proposed office units. The minimum values for total thermal loads depend on thermal performance of building envelope. The proposed design of building envelope of office unit has the flexibility to change its angle of rotation and enclosure angle between the forming triangles in order to enhance the thermal performance of building envelope as it was modeled in grasshopper application. The optimization for enhancing thermal performance is performed according to the following code:

I. Attach fitness function input with total thermal loads form the output of honeybee read EP result component which previously resulted from energy simulation (see fig. 5-23,24).

II. For genome input of Galapagos, attach it to the parameters of building envelope lattice which are in this case the angle of rotation inside the circle and the enclosure angle between the forming triangles.

III. Before starting optimization process, it should be adjusted to perform the process to study the variations of genome parameters in order to reach the minimum value of fitness function (see fig. 5-25).

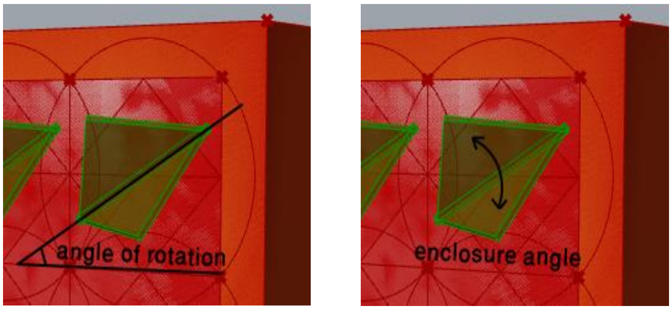


Figure 5-23 Angle Of Rotation And Enclosure Angle For Each Unit of Building Envelope Lattice
Source: Author.

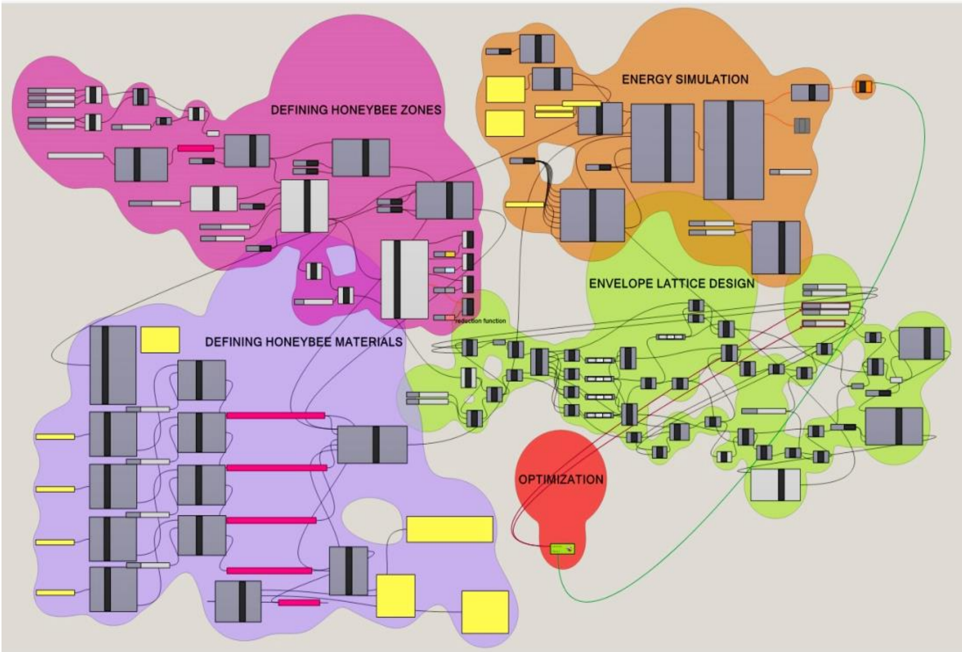


Figure 5-24 Grasshopper Preview Of Parametric Functions For Optimimzation Process Framework
Source: Author.

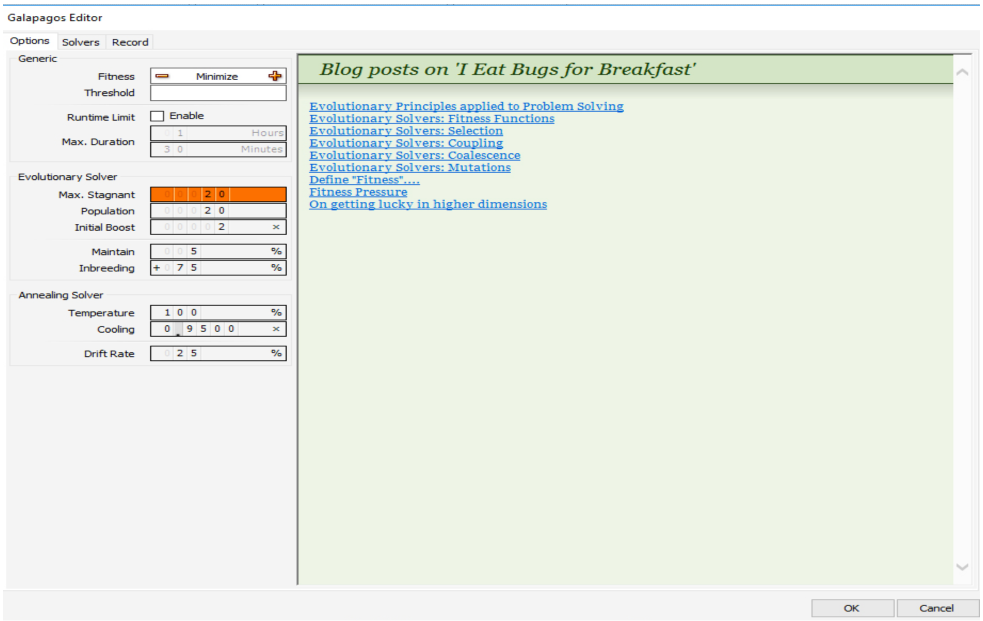


Figure 5-25 Grasshopper Preview Of Galapagos settings to achieve minimum values for total thermal During The Optimization Process
Source: Author.

5.5.2 Sixth Step: Repeating Optimization Process

The optimization process is set to repeat itself and perform energy simulation with other values for genome input of Galapagos which are both angle of rotation and the enclosure angle of the building envelope lattice. Every time optimization process is repeated, a new value for total thermal load is calculated. So, a comparison between the calculated variables could be done to reach the optimum solutions to minimize this value (see fig. 5-26,27).

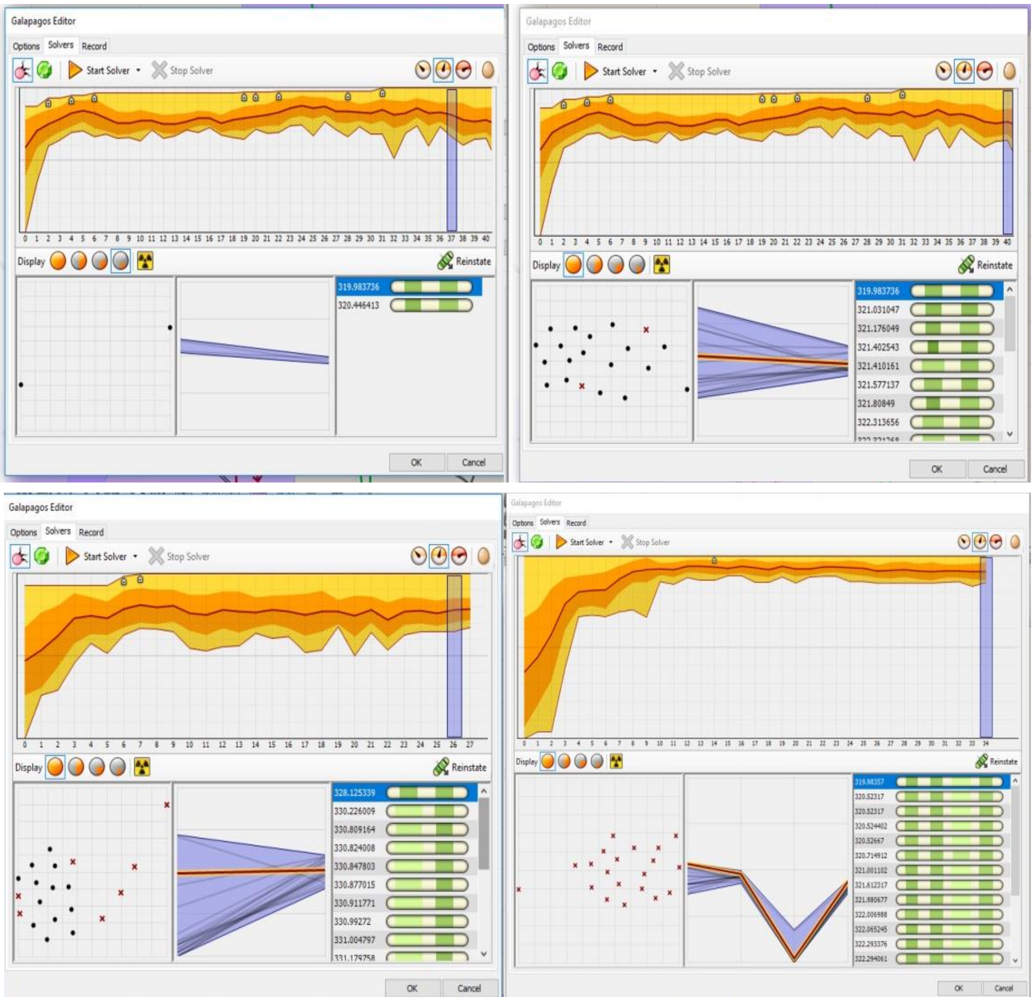


Figure 5-26 Grasshopper Preview Of Generations of Solutions calculated by biomimetic optimization algorithms
Source: Author.

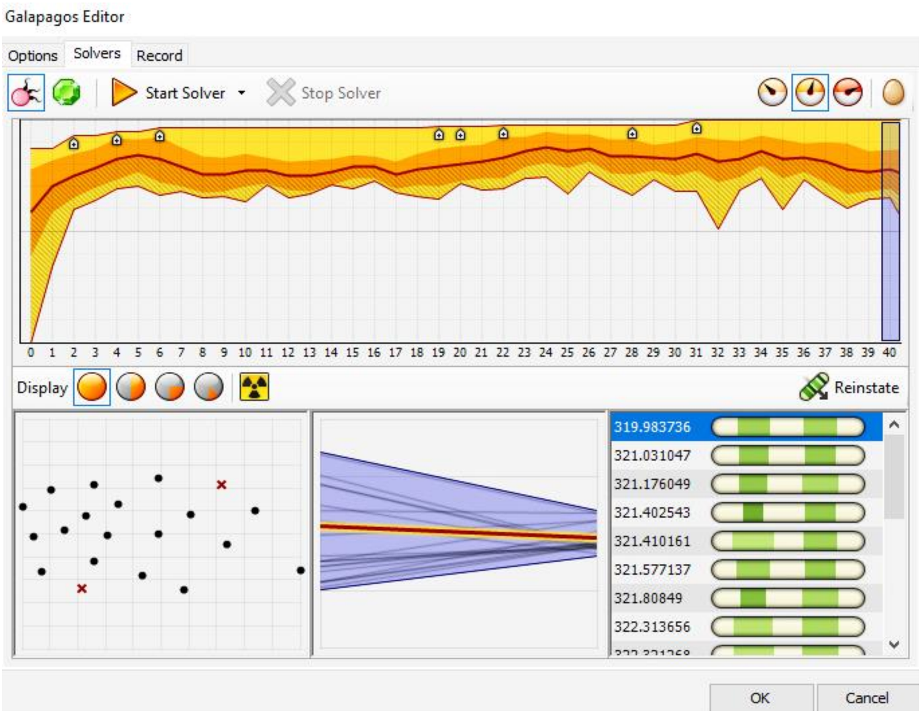


Figure 5-27 Grasshopper Preview Of The Optimum Solution calculated by biomimetic optimization algorithms
Source: Author.

5.6 Optimization Results

Results of optimization process are calculated by Galapagos as an optimization engine, EnergyPlus as a simulation engine, and Grasshopper as a host for visualizing the resulted generations. The results for optimal solution to enhance thermal performance of building envelope by using genetic algorithms as biomimetic optimization algorithm is shows in seventh step of the optimization process as follows:

5.6.1 Seventh Step: Results of Optimization Process

For the optimization process the results are as following: in the default state before starting the optimization process, the value of total thermal loads for glazing system assigned to windows of office unit in the proposed duration of the year without applying the proposed design of building envelope lattice is calculated in the beginning of the process. Then resulted value for minimum total thermal loads achieved by Galapagos component after applying the proposed design of building envelope lattice is calculated to define the difference in total thermal loads after applying optimization process.

According to optimization process results, the rotation angle of building envelope lattice units is adjusted to defined degrees which are the desired value to reach the minimum value of total thermal loads. The enclosure angle between the forming triangles is adjusted to defined degrees which is the desired value to reach the minimum value of total thermal loads (see fig. 5-28).

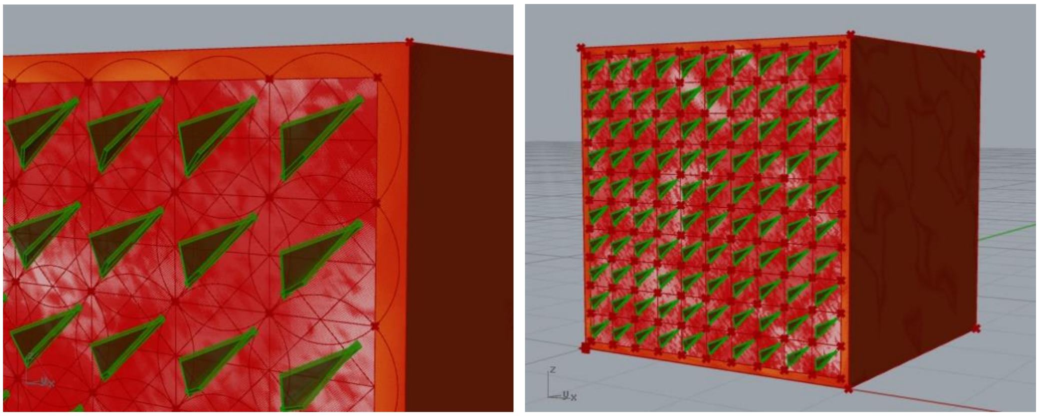


Figure 5-28 The Optimum Solution Geometry for Building Envelope Lattice Units after Applying Optimum values for angle of Rotation and Enclosure Angle
Source: Author.

Optimization process is applied for both southern and western façades for the selected case studies to identify the total thermal loads reduction, angle of rotation and enclosure angle for building envelope.

5.7 Case Studies

The choosing of case studies to perform optimization process depends on the following limitations:

- For the case studies located in Egypt: the selected cities should represent different locations in Egypt to cover the climate change in the whole country as possible.

- For the case studies located outside Egypt: the selected cities should represent different locations in the world to represent the climate changes in the whole world as possible.

The selected cities are as following (see fig. 5-29):

1- Mersa Matruh city located in the north of Egypt, Africa.
2- Sheikh Zayed city located in the middle of Egypt, Africa.
3- Aswan city located in the south of Egypt, Africa.
4- Paris city located in France, Europe.
5- Riyadh city located in Kingdom of Saudi Arabia (KSA), Asia.
6- New York City located in United States of America (USA), North America.

Figure 5-29 Locations of selected case studies.
Source: Author.

5.7.1 First Case Study: Mersa Matruh City

5.7.1.1 City Information

The following table represents the information of the city that identifies location, DMS coordinates, and weather in July which is the analysis period of the proposed optimization process (see tab. 5-2).

Table 5-2. Mersa Matruh city data.
Source: Author.

No.	Item	Data
1	Location	North of Egypt, Africa
2	DMS coordinates	31° 21' 15.6348" N 27° 14' 14.3376" E[1].
3	Weather in July	The summers are warm, muggy, arid, and clear and the winters are cool, dry, windy, and mostly clear. Daily high temperatures increase from 29° C to 30°C[2].

5.7.1.2 Optimization Results for Mersa Matruh city

For the optimization process of both south and west façade of the proposed office building: total thermal loads are calculated in the default state before applying optimization process then after applying optimization process the total thermal loads are calculated again and therefore values of both the rotation angle of building envelope lattice units and enclosure angle between the forming triangles of the building envelope lattice are defined for the optimum solution to achieve the minimum total thermal loads (see fig. 5-30).

The following table represents the results before and after optimization process (see tab. 5-3):

[1] https://www.latlong.net/place/mersa-matruh-qism-moursy-matrouh-matrouh-egypt-3576.html
[2] https://weatherspark.com/m/94262/7/Average-Weather-in-July-in-Mersa-Matruh-Egypt#Sections-Clouds

Table 5-3. Mersa Matruh city optimization process results.
Source: Author.

No.	City Mersa Matruh	Façade South	Façade West
1	Total thermal loads for building envelope default state before applying optimization process	329.51 KWH	321.76 KWH
2	Total thermal loads for building envelope after applying optimization process	285.04 KWH	263.10 KWH
3	Angle of rotation of envelope lattice units	43 degrees	129 degrees
4	Enclosure Angle of envelope lattice units	21 degrees	11 degrees

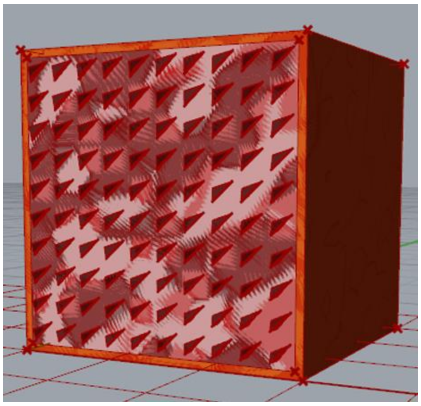
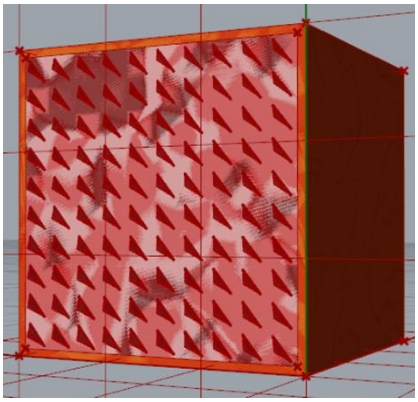



Figure 5-30 left: Optimization result of southern façade of building envelope in Mersa Matruh city. Right: Optimization result of western façade of building envelope in Mersa Matruh city.
Source: Author.

5.7.2 Second Case Study: Sheikh Zayed City

5.7.2.1 City Information

The following table represents the information of the city that identifies location, DMS coordinates, and weather in July which is the analysis period of the proposed optimization process (see tab. 5-4).

Table 5-4. Sheikh Zayed city data.
Source: Author.

No.	Item	Data
1	Location	Middle of Egypt, Africa
2	DMS coordinates	30° 3' 21.6756" N 30° 58' 35.9004" E [1].
3	Weather in July	Hot summer month in Sheikh Zayed City, Egypt, with average temperature fluctuating between 34.4°C (93.9°F) and 20.1°C (68.2°F). [2].

5.7.2.2 Optimization Results for Sheikh Zayed city

For the optimization process of both south and west façade of the proposed office building: total thermal loads are calculated in the default state before applying optimization process then after applying optimization process the total thermal loads are calculated again and therefore values of both the rotation angle of building envelope lattice units and enclosure angle between the forming triangles of the building envelope lattice are defined for the optimum solution to achieve the minimum total thermal loads (see fig. 5-31).

The following table represents the results before and after optimization process (see tab. 5-5):

[1] https://www.latlong.net/place/sheikh-zayed-city-giza-governorate-egypt-8915.html
[2] https://www.weather-atlas.com/en/egypt/sheikh-zayed-city-weather-july

Table 5-5. Sheikh Zayed city optimization process results.
Source: Author.

No.	**City** **Sheikh Zayed**	**Façade** **South**	**Façade** **West**
1	Total thermal loads for building envelope default state before applying optimization process	366.36 KWH	358.53 KWH
2	Total thermal loads for building envelope after applying optimization process	319.98 KWH	284.50 KWH
3	Angle of rotation of envelope lattice units	43 degrees	141 degrees
4	Enclosure Angle of envelope lattice units	21 degrees	20 degrees

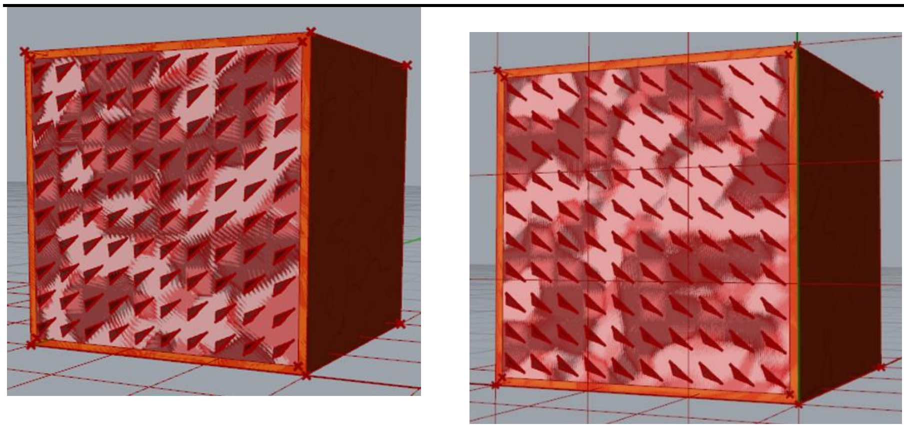


Figure 5-31 left: Optimization result of southern façade of building envelope in Sheikh Zayed city. Right: Optimization result of western façade of building envelope in Sheikh Zayed city.
Source: Author.

5.7.3 Third Case Study: Aswan City

5.7.3.1 City Information

The following table represents the information of the city that identifies location, DMS coordinates, and weather in July which is the analysis period of the proposed optimization process (see tab. 5-6).

Table 5-6. Aswan city data.
Source: Author.

No.	Item	Data
1	Location	South of Egypt, Africa
2	DMS coordinates	24° 5' 20.1768" N 32° 53' 59.3880" E[1].
3	Weather in July	an extremely hot summer month, with temperature in the range of an average high of 41.1°C (106°F) and an average low of 26°C (78.8°F). [2].

5.7.3.2 Optimization Results for Aswan city

For the optimization process of both south and west façade of the proposed office building: total thermal loads are calculated in the default state before applying optimization process then after applying optimization process the total thermal loads are calculated again and therefore values of both the rotation angle of building envelope lattice units and enclosure angle between the forming triangles of the building envelope lattice are defined for the optimum solution to achieve the minimum total thermal loads (see fig. 5-32).

The following table represents the results before and after optimization process (see tab. 5-7):

[1] https://www.latlong.net/place/aswan-aswan-governorate-egypt-24191.html
[2] https://www.weather-atlas.com/en/egypt/aswan-weather-july

Table 5-7. Aswan city optimization process results.
Source: Author.

No.	City Aswan	Façade South	Façade West
1	Total thermal loads for building envelope default state before applying optimization process	795.80 KWH	867.14 KWH
2	Total thermal loads for building envelope after applying optimization process	725.71 KWH	688.22 KWH
3	Angle of rotation of envelope lattice units	47 degrees	141 degrees
4	Enclosure Angle of envelope lattice units	22 degrees	20 degrees

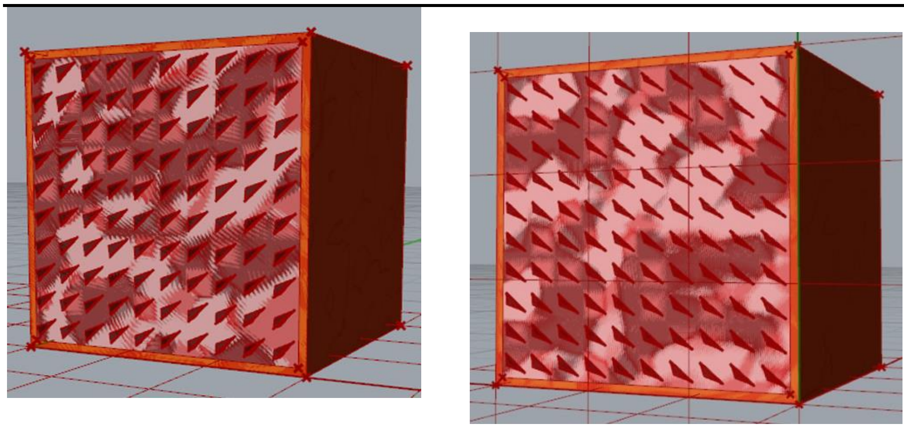


Figure 5-32 left: Optimization result of southern façade of building envelope in Aswan city. Right: Optimization result of western façade of building envelope in Aswan city.
Source: Author.

5.7.4 Fourth Case Study: Paris City

5.7.4.1 City Information

The following table represents the information of the city that identifies location, DMS coordinates, and weather in July which is the analysis period of the proposed optimization process (see tab. 5-8).

Table 5-8. Paris city data.
Source: Author.

No.	Item	Data
1	Location	France, Europe
2	DMS coordinates	48° 51' 52.9776" N 2° 20' 56.4504" E[1].
3	Weather in July	The hottest month in Paris with moderately warm temperatures between 16°C (60.8°F) and 25°C (77°F). [2].

5.7.4.2 Optimization Results for Paris city

For the optimization process of both south and west façade of the proposed office building: total thermal loads are calculated in the default state before applying optimization process then after applying optimization process the total thermal loads are calculated again and therefore values of both the rotation angle of building envelope lattice units and enclosure angle between the forming triangles of the building envelope lattice are defined for the optimum solution to achieve the minimum total thermal loads (see fig. 5-33).

The following table represents the results before and after optimization process (see tab. 5-9):

[1] https://www.latlong.net/place/paris-france-1666.html
[2] https://www.weather-atlas.com/en/france/paris-weather-july

Table 5-9. Paris city optimization process results.
Source: Author.

No.	**City** **Paris**	**Façade** **South**	**Façade** **West**
1	Total thermal loads for building envelope default state before applying optimization process	75.84 KWH	75.85 KWH
2	Total thermal loads for building envelope after applying optimization process	56.93 KWH	60.88 KWH
3	Angle of rotation of envelope lattice units	43 degrees	141 degrees
4	Enclosure Angle of envelope lattice units	21 degrees	20 degrees

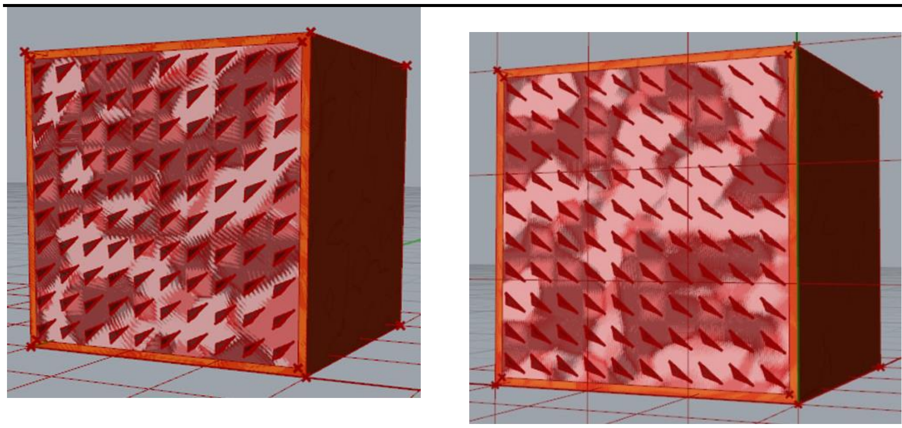


Figure 5-33 left: Optimization result of southern façade of building envelope in Paris city. Right: Optimization result of western façade of building envelope in Paris city.
Source: Author.

5.7.5 Fifth Case Study: Riyadh City

5.7.5.1 City Information

The following table represents the information of the city that identifies location, DMS coordinates, and weather in July which is the analysis period of the proposed optimization process (see tab. 5-10).

Table 5-10. Riyadh city data.
Source: Author.

No.	Item	Data
1	Location	KSA, Asia
2	DMS coordinates	24° 46' 27.3540" N 46° 44' 18.9096" E[1].
3	Weather in July	blistering summer month in Riyadh, Saudi Arabia, with temperature in the range of an average low of 29.3°C (84.7°F) and an average high of 43.5°C (110.3°F)[2].

5.7.5.2 Optimization Results for Riyadh city

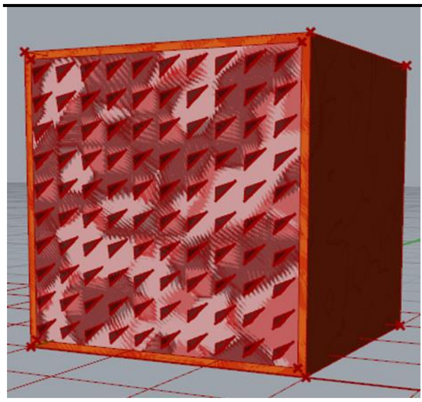
For the optimization process of both south and west façade of the proposed office building: total thermal loads are calculated in the default state before applying optimization process then after applying optimization process the total thermal loads are calculated again and therefore values of both the rotation angle of building envelope lattice units and enclosure angle between the forming triangles of the building envelope lattice are defined for the optimum solution to achieve the minimum total thermal loads (see fig. 5-34).

The following table represents the results before and after optimization process (see tab. 5-11):

[1] https://www.latlong.net/place/riyadh-saudi-arabia-7406.html
[2] https://www.weather-atlas.com/en/saudi-arabia/riyadh-weather-july

Table 5-11. Riyadh city optimization process results.
Source: Author.

No.	City Riyadh	Façade South	Façade West
1	Total thermal loads for building envelope default state before applying optimization process	842.39 KWH	890.15 KWH
2	Total thermal loads for building envelope after applying optimization process	764.23 KWH	748.25 KWH
3	Angle of rotation of envelope lattice units	39 degrees	141 degrees
4	Enclosure Angle of envelope lattice units	17 degrees	20 degrees



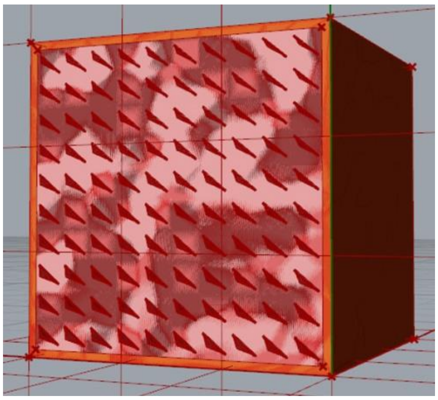


Figure 5-34 left: Optimization result of southern façade of building envelope in Riyadh city. Right: Optimization result of western façade of building envelope in Riyadh city.
Source: Author.

5.7.6 Sixth Case Study: New York City

5.7.6.1 City Information

The following table represents the information of the city that identifies location, DMS coordinates, and weather in July which is the analysis period of the proposed optimization process (see tab. 5-12).

Table 5-12. New York city data
Source: Author.

No.	Item	Data
1	Location	USA, North America
2	DMS coordinates	40° 43' 50.1960" N 73° 56' 6.8712" W[1].
3	Weather in July	July is the hottest month with temperatures ranging between 20°C (68°F) and 29°C (84.2°F) and sometimes rising to 32°C (89.6°F) [2].

5.7.6.2 Optimization Results for New York city

For the optimization process of both south and west façade of the proposed office building: total thermal loads are calculated in the default state before applying optimization process then after applying optimization process the total thermal loads are calculated again and therefore values of both the rotation angle of building envelope lattice units and enclosure angle between the forming triangles of the building envelope lattice are defined for the optimum solution to achieve the minimum total thermal loads (see fig. 5-35).

The following table represents the results before and after optimization process (see tab. 5-13):

[1] https://www.latlong.net/place/new-york-city-ny-usa-1848.html
[2] https://www.weather-atlas.com/en/new-york-usa/new-york-weather-july

Table 5-13. New York city optimization process results
Source: Author.

No.	**City** **New York**	**Façade** **South**	**Façade** **West**
1	Total thermal loads for building envelope default state before applying optimization process	326.97 KWH	326.92 KWH
2	Total thermal loads for building envelope after applying optimization process	276.86 KWH	270.90 KWH
3	Angle of rotation of envelope lattice units	43 degrees	141 degrees
4	Enclosure Angle of envelope lattice units	21 degrees	20 degrees

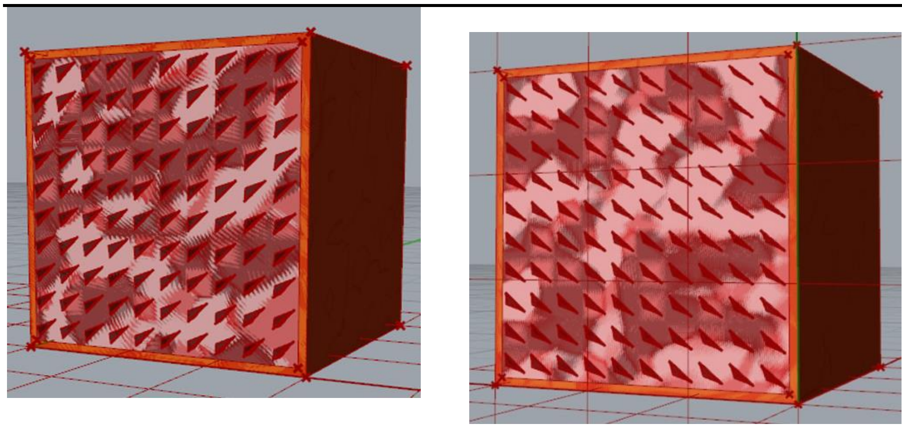


Figure 5-35 left: Optimization result of southern façade of building envelope in New York city. Right: Optimization result of western façade of building envelope in New York city.
Source: Author.

5.7 Summary

In this chapter a new design methodology was presented to enhance thermal performance of digital design of building envelope by using optimization process. The proposed optimization framework provides optimization concept, methodology, two types of design variables, limitations of optimization process, Rhinoceros and Grasshopper applications as parametric platforms for digital modeling of building envelope, and EnergyPlus as a simulation engine for the optimization process. The seven steps of optimization process for building envelope are discussed in detail to explain how building envelope is modeled, tested, and optimized to minimize thermal performance.

5.8 Conclusion

The new design methodology presented in this chapter is based on an optimization concept which emerged from the combination between building envelope variables, biomimicry concept, and biomimetic optimization algorithms. The details of the proposed optimization concept are presented in the following figure (see fig. 5-36):

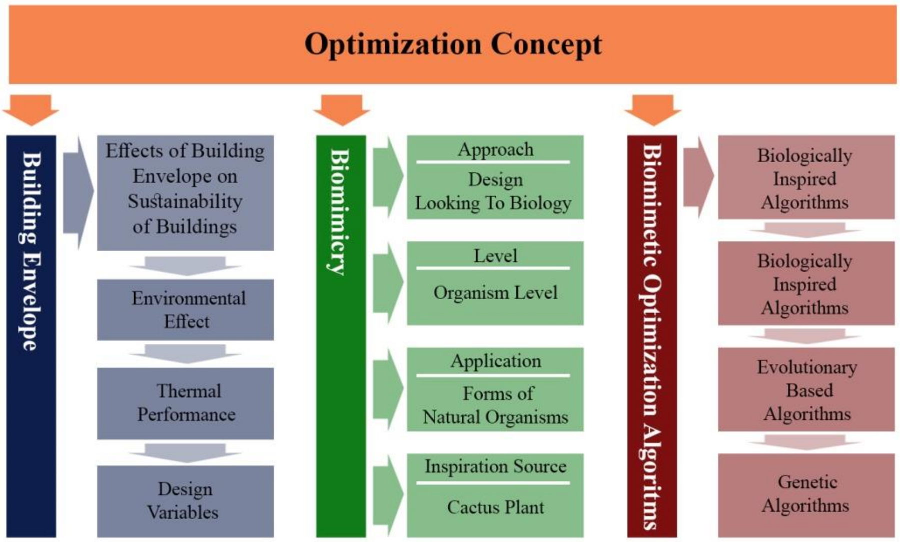


Figure 5-36 Components of Optimization Process Concept
Source: Author.

Through the research methodology, the results emerged from an optimization process by using the proposed design of building envelope lattice for the proposed design of office unit and assigned weather conditions. The optimization process was applied for the selected cities for both south and west facades. Results of the optimization process indicate that the total thermal loads when using the proposed building envelope design are less than the total thermal loads of the default state before optimization process. According to the previous results, the proposed lattice design with assigned values for angle of rotation and enclosure angle by using biomimetic optimization algorithms such as genetic algorithms enhances thermal performance of building envelope were defined for both south and west façade in the selected cities that located in different countries all over the world.

The following tables represent the total thermal loads reduction that resulted from the optimization process (see tab. 5-14,15):

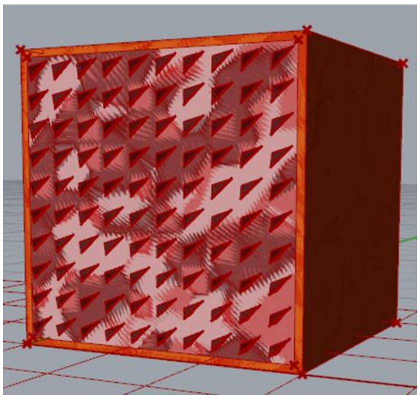
Table 5-14. Results of the optimization process for the southern façade in case studies. Source: Author.

No.	City	Total thermal loads for building envelope before applying the optimization process (KWH)	Total thermal loads for building envelope after applying the optimization process (KWH)	Reduction value of total thermal loads	Reduction Ratio of total thermal loads
1	Mersa Matruh	329.51	285.04	44.47	13.49 %
2	Sheikh Zayed	366.36	319.98	46.38	12.65 %
3	Aswan	795.80	725.71	70.09	08.80 %
4	Paris	75.84	56.93	18.91	24.93 %
5	Riyadh	842.39	764.23	78.16	09.27 %
6	New York	326.97	276.86	50.11	15.32 %

Table 5-15. Results of the optimization process for the western façade in case studies. Source: Author.

No.	City	Total thermal loads for building envelope before applying the optimization process (KWH)	Total thermal loads for building envelope after applying the optimization process (KWH)	Reduction value of total thermal loads	Reduction Ratio of total thermal loads
1	Mersa Matruh	321.76	263.10	58.66	18.23%
2	Sheikh Zayed	358.53	284.50	74.03	20.64%
3	Aswan	867.14	688.22	178.92	20.63%
4	Paris	75.85	60.88	14.97	19.73%
5	Riyadh	890.15	748.25	141.9	15.94 %
6	New York	326.92	270.90	56.02	17.13%

While the following tables represent the angle of rotation and enclosure angle of the proposed building envelope lattice units which identify the optimal solution of building envelope lattice design to achieve the minimum total thermal loads through the optimization process (see fig. 5-37) (see tab. 5-16):



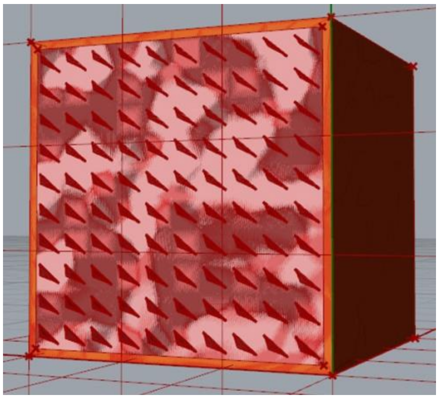


Figure 5-37 left: Angle of rotation and enclosure angle for the optimum solution for the southern façade of building envelope. Right: Angle of rotation and enclosure angle for the optimum solution for the western façade of building envelope. Source: Author.

Table 5-16. Angle of rotation and enclosure angles of the proposed building envelope lattice units that represent the optimum solution.
Source: Author.

No.	**City**	**Southern facade**		**Western facade**	
		Angle of rotation of the proposed building envelope lattice units for the optimum solution (Degrees)	Enclosure angle of the proposed building envelope lattice units for the optimum solution (Degrees)	Angle of rotation of the proposed building envelope lattice units for the optimum solution (Degrees)	Enclosure angle of the proposed building envelope lattice units for the optimum solution (Degrees)
1	Mersa Matruh	43	21	129	11
2	Sheikh Zayed	43	21	141	20
3	Aswan	47	22	141	20
4	Paris	43	21	141	20
5	Riyadh	39	17	141	20
6	New York	43	21	141	20

Chapter Six
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6.1 Conclusions

The research based on presenting a design methodology to enhance thermal performance of building envelope. The proposed design methodology emerged from the integration between many ingredients which were: digital design of building envelope, environmental effect of building envelope on building sustainability, thermal regulation in buildings, biomimicry concept, biomimetic optimization algorithms and energy simulation in building sample.

The literature review which presents the capabilities of building envelope, biomimicry, energy simulation, digital design and biomimetic optimization algorithms for enhancing thermal performance in many ways indicates that the combination between them all affects both building envelope design and thermal performance.

Biophilic design which emerged from biofilia effect reflects great capabilities which encourage architects to use it in order to solve environmental problems for built environment. Biomimicry as a leading pattern from biophilic design patterns is the most pattern used for built environment treatments. The inspiration source for the optimization process plays a great role in the process as it can control which direction for optimization to move towards. It indicates as well the approach, level, and application of biomimicry to use in order to achieve suitable optimum solutions.

Algorithms have great mathematical potentials for solving complicated problems. Architects can use these potentials for solving environmental problems in built environment by applying the optimization concept to achieve the optimum solutions for each problem. Genetic algorithm has a great importance in this field of study as it can be used for controlling the optimization process for many environmental problems.

According to the proposed optimization process, input data for the assigned case studies, research variables and limitations of the new design methodology of building envelope provides a thermal performance reduction of building envelope in southern facade varies from 08.80 % to 24.93 % lower than the thermal performance for the same case studies' building envelope without any treatments which affect thermal performance (see fig. 6-1).

The optimum solution for enhancing thermal performance in southern envelope has angle of rotation varies from 39 degrees to 47 degrees and an enclosure angle varies from 17 degrees to 22 degrees (see fig. 6-2,3).

On other hand, thermal performance reduction of building envelope in western facade varies from 15.94 % to 20.64 % lower than the thermal performance for the same case studies' building envelope without any treatments which affect thermal performance.

The optimum solution for enhancing thermal performance in western envelope has angle of rotation varies from 129 degrees to 114 degrees and an enclosure angle varies from 11 degrees to 20 degrees.

The assigned values of both angel of rotation and enclosure angle of the proposed lattice unit for the building envelope help architects to use in forming building envelope that can enhance thermal performance in both southern and western façade.

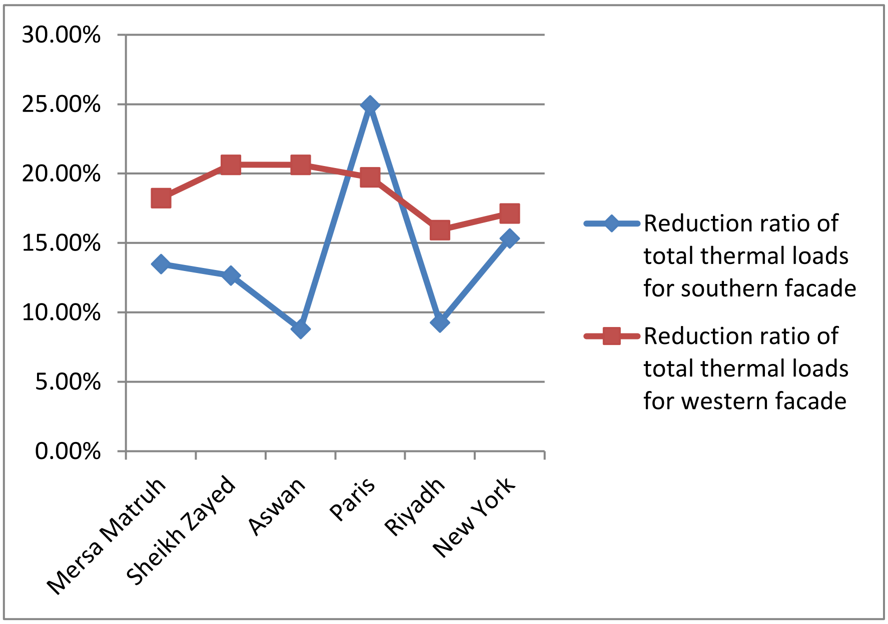
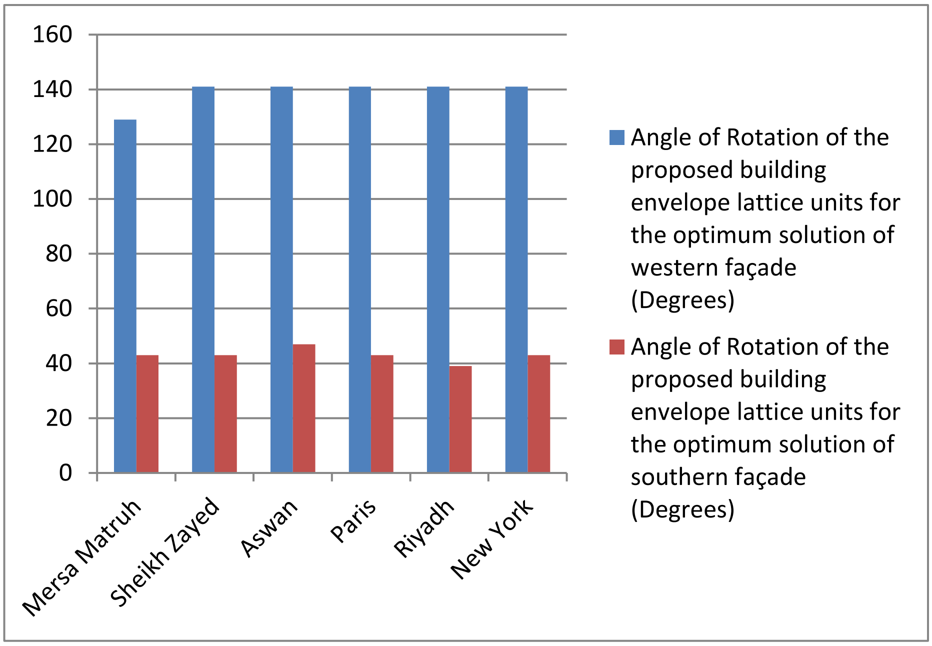


Figure 6-1 : Reduction ratio chart of total thermal loads for both southern and western facades.



Source: Author.

Figure 6-2 : Angle of rotation of the proposed building envelope lattice units for both southern and western facades.

Source: Author.

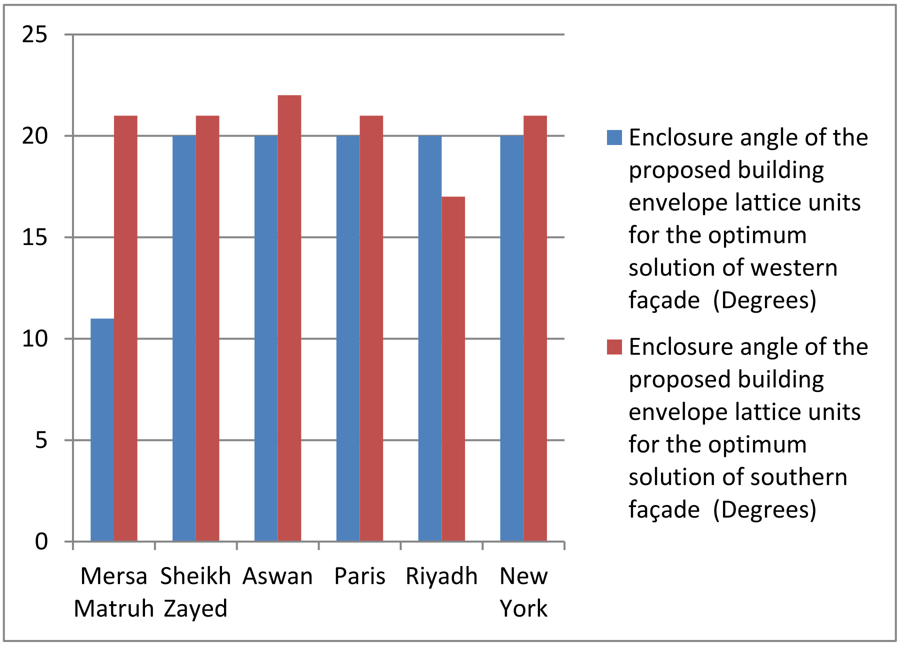


Figure 6-3 : Enclosure angle of the proposed building envelope lattice units for both southern and western facades.

Source: Author.

The new design methodology that was proposed for the optimization process of building envelope lattice units could be considered as an effective treatment to enhance thermal performance through using biomimetic optimization algorithms. So the integration between biomimicry, digital design, and optimization algorithms is an effective way to evaluate and find optimal solution for building envelope design to enhance thermal performance of it.

According to literature review findings and the new design methodology a framework for the new building envelope lattice with an optimization process to enhance thermal performance could be presented as a conclusion for research as follows (see fig. 6-4,5):

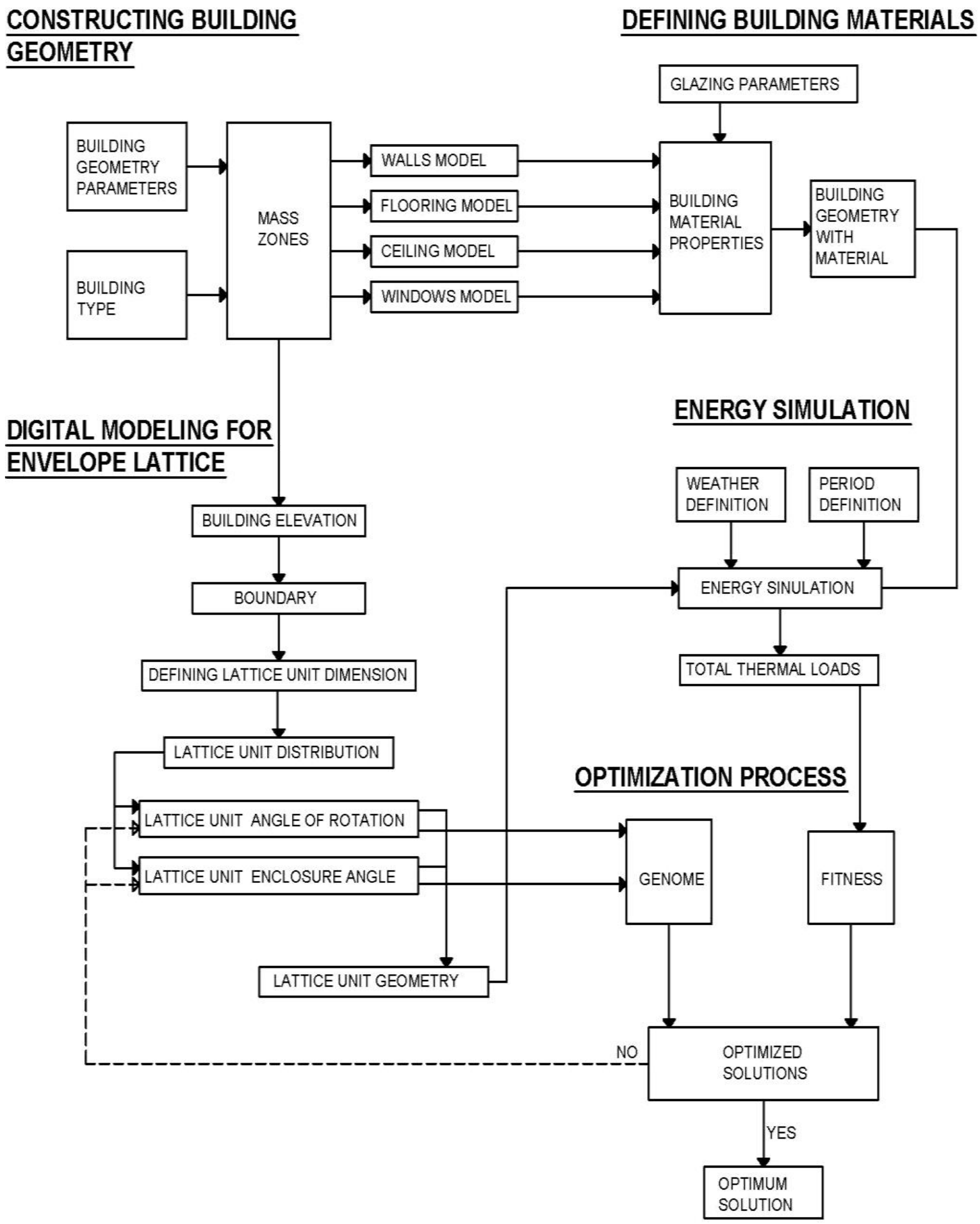


Figure 6-4 : Enhancing thermal performance for building envelope framework.
Source: Author.

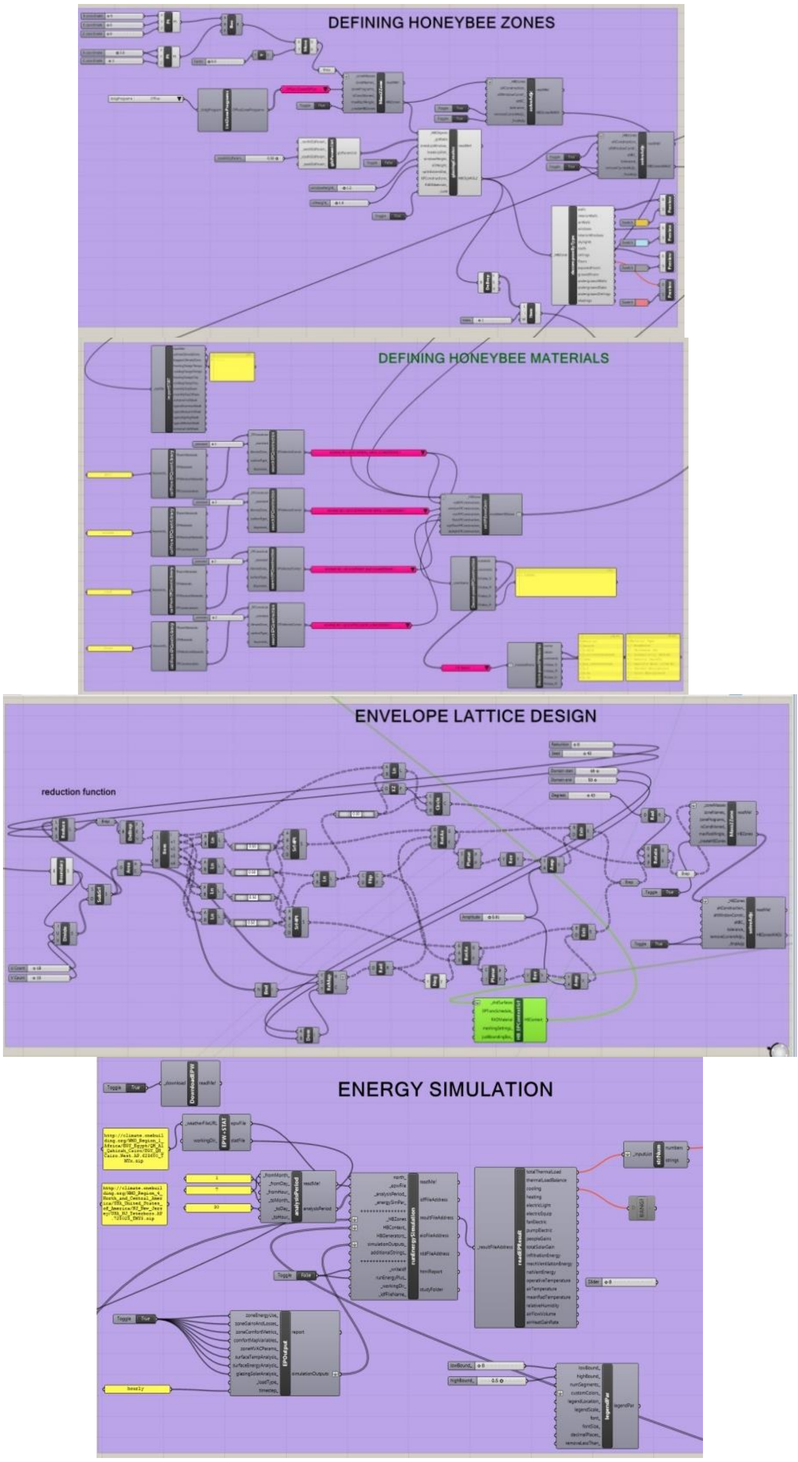


Figure 6-5 : Application of the proposed enhancing thermal performance for building envelope framework.
Source: Author.

According to reduction in total thermal loads in both southern and western façade of the proposed building envelope in the assigned case studies, and as a conclusion from research results, the proposed design methodology for building envelope to enhance thermal performance by using biomimetic optimization algorithms managed to provide significant optimal solutions for building envelope design with thermal performance improvements. So, it can be considered as a valid methodology for enhancing thermal performance of building envelope.

6.2 Recommendations

For further research directions, it could include different types of biomimetic optimization algorithms to develop new types with new inspiration concepts to generate innovative solutions for environmental problems. The following tips could be useful for researchers in this field:

1- The proposed design methodology offers a large number of chances and opportunities which attracts future researchers to use its capabilities in improving and enhancing many factors in built environment such as enhancing daylight qualities, Acoustics in buildings, shading devices, life cycle cost.

2- Research limitations may be reduced in the future researches in order to investigate new variables such as reduction ratio of building envelope units, number of seeds of building envelope, and shape of building envelope in optimization process.

3- Whenever there are more researches in this field, there is a rapid development of the optimization tools to cope with research's needs. Future researches in this field push the development circle to include both optimization tools and digital applications. The development of the optimization tools will help architects to work with more accuracy, time saving, easy in using the application and powerful algorithms as well.

The awareness and importance of optimization concept should be learned to architectural students in architectural schools and departments to increase the awareness about built environment problems and how to overcome these problems by innovative and optimal design solutions in terms of sustainability of building approach.

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وخوارزميات التحسين طريقة فعالة لتقييم وإيجاد الحل الأمثل لبناء تصميم غلاف المبنى لتحسين الأداء الحراري له. وبناء على ذلك فإن منهجية التصميم المقترحة لغلاف المبنى لتحسين الأداء الحراري باستخدام خوارزميات تعزيز مثالية المحاكاة الحيوية تمكنت من توفير حلول مثالية مهمة لتصميم غلاف المبنى مع تحقيق تحسينات فى الأداء الحراري. لذلك يمكن اعتبارها منهجية صالحة لتعزيز الأداء الحراري لغلاف المبنى.

لمزيد من الاتجاهات البحثية فى هذا المجال ، يمكن أن تشمل الابحاث المستقبلية دراسة أنواعًا مختلفة من خوارزميات تعزيز مثالية المحاكاة الحيوية لتطوير أنواع جديدة بمفاهيم إلهام جديدة لتوليد حلول مبتكرة للمشاكل البيئية. تقدم منهجية التصميم المقترحة عددًا كبيرًا من الفرص التي تجذب الباحثين المستقبليين لاستخدام قدراتها في تحسين وتعزيز العديد من العوامل في البيئة المبنية مثل تعزيز معدلات ضوء النهار، ومعدلات الصوتيات في المباني، وأجهزة التظليل ،وتكلفة دورة الحياة فى المبانى.

لا يمكن للمصممين بمفردهم وقدراتهم الخاصة أن يتصوروا ويتنبأوا بنتائج أداء الخوارزمية وفقًا للمعادلات الرياضية المعقدة والعملية ، لذلك تفتح الخوارزميات مصدرًا ضخمًا للمفاهيم والأفكار الجديدة والمبتكرة للمصممين. يتم استخدام الخوارزميات ليس فقط لإنتاج نموذج رقمي لأي مفهوم مرغوب فيه ، بل يتم استخدامه أيضًا لاختيار وتحديد الحل الأمثل لبيانات الإدخال والظروف التي يختارها المصممون لحلها. يمكن أن تستلهم المفاهيم والأفكار التي تم تصميمها بشكل جانبي باستخدام الخوارزميات من الطبيعة باستخدام المحاكاة الحيوية. العلاقة بين استخدام الخوارزميات للتحسين والمحاكاة الحيوية للإلهام تسمى خوارزميات تعزيز مثالية المحاكاة الحيوية. هناك عدد مختلف من خوارزميات تعزيز مثالية المحاكاة الحيوية الناجحة. يمكن تقسيم خوارزميات تعزيز مثالية المحاكاة الحيوية (المستوحاة من الطبيعة) إلى فئتين رئيسيتين. المجموعة الرئيسية الأولى هي خوارزميات مستوحاة بيولوجيًا تعتمد على الإستلهام من الكائن الحي وتنقسم هذه الفئة إلى خوارزميات تطورية وخوارزميات تعتمد على أسراب وخوارزميات قائمة على البيئة. الفئة الرئيسية الثانية هي الخوارزميات القائمة على الفيزياء والكيمياء والتي ليست خوارزميات مستوحاة من الناحية البيولوجية ولكنها لا تزال خوارزميات مستوحاة من الطبيعة.

يقدم الفصل الخامس دراسة تحليلية لعملية تعزيز مثالية منهجية تصميم جديدة لتعزيز الأداء الحراري للتصـــميم الرقمي لغلاف المبنى. يحتوى إطار العمل فى عملية التعزيز المقترحة على كل من مفهوم التحســين ، والمنهجية ، ونوعين من متغيرات التصــميم ، وقيود عملية التحســين ، وتطبيقات Rhinoceros و Grasshopper كمنصـــات بارامترية للنمذجة الرقمية لغلاف المبنى ، و EnergyPlus كمحرك محاكاة لعملية التحســين. تتكون عملية تعزيز المثالية من سـبعة مراحل حيث تتم مناقشـة الخطوات السـبع لعملية التحسـين غلاف المبنى بالتفصــيل لتوضــيح كيفية تصــميم غلاف المبنى واختباره وتحســينه لتقليل الأداء الحراري. من خلال منهجية البحث ، ونتائج عملية تعزيز المثالية عن طريق اســتخدام التصميم المقترح لشبكة غلاف المبنى للتصميم المقترح للوحدة المكتبية المختارة وظروف الطقس المعينة تمكن المصـــمم من تقليل الأحمال الحرارية الإجمالية عن إجمالي الأحمال الحرارية للحالة الافتراضـــية للوحدة المكتبية المختارة قبل عملية تعزيز المثالية لتحســـين الداء الحرارى. وفقًا للنتائج الســـابقة ، فإن تصـــميم غلاف المبنى الرقمى المقترح مع القيم المخصــصـــة لزاوية الدوران والزاوية البينية للواحدات المكونة له باســتخدام خوارزميات المحاكاة الحيوية مثل الخوارزميات الجينية يحسن الأداء الحراري لغلاف المبنى.

يعرض الفصل السادس نتائج وتوصيات البحث. اعتمد البحث على تقديم منهجية تصميم لتحسين الأداء الحراري لغلاف المبنى. نشأت منهجية التصميم المقترحة من التكامل بين العديد من المكونات وهى: التصميم الرقمي لغلاف المبنى ، والتأثير البيئي لغلاف المبنى على استدامة المبنى ، والتنظيم الحراري في المباني ، ومفهوم المحاكاة الحيوية ، وخوارزميات تعزيز مثالية المحاكاة الحيوية ومحاكاة الطاقة في البيئة المبنية. تؤكد مراجعة الأدبيات التي تم عرضها الى ان الجمع بين إمكانات غلاف المباني والمحاكاة الحيوية ومحاكاة الطاقة والتصميم الرقمي وخوارزميات تعزيز مثالية المحاكاة الحيوية تؤثر بطرق عديدة على كل من تصميم غلاف المبنى والأداء الحراري. وفقًا لعملية التحسين المقترحة ، و توفر بيانات الإدخال الخاصة بعد ستة مدن مختارة كحالات دراسية فى اماكن مختلفة فى العالم ، ومتغيرات البحث وحدود منهجية التصميم الجديدة لمغلف المبنى انخفاضًا في الأداء الحراري لغلاف المبنى أقل من الأداء الحراري لغلاف مبنى دراسة الحالة نفسه بدون أي معالجات تؤثر على الأداء الحراري. لذا يعد التكامل بين المحاكاة الحيوية والتصميم الرقمي

يتكون البحث من ستة فصول على النحو التالي:

يقدم الفصل الأول مراجعة أدبية لأحدث الدراسات في مجال البحث حيث يجذب مجال الحفاظ على الطاقة مزيدًا من الاهتمام ويشجع الباحثين على استخدام استراتيجيات مختلفة لتحقيق ذلك. ان الاستهلاك الكلي للطاقة في العالم ينتج عن ثلاثة أسباب رئيسية هي الصناعات والمباني ووسائل النقل. تم تطوير الطرق القديمة لحساب أداء الطاقة بفضل تطبيقات تكنولوجيا المعلومات، حيث تسمى العملية الجديدة المستخدمة لحساب أداء الطاقة للمباني بمحاكاة الطاقة أو نمذجة بناء الطاقة. يستطيع المهندسون المعماريون التنبؤ وتحليل استهلاك الطاقة الناتج في أي جزء من المبنى من خلال المراحل المختلفة لعملية محاكاة الطاقة أثناء عملية التصميم ويمكن استخدام ذلك لتغيير استهلاك الطاقة حسب الحاجة في الموقع المحدد في المبنى. تمد ميزة محاكاة الطاقة فى المبانى المهندسين بالعديد من الافكار القابلة للتطبيق من أجل تحقيق أقصى استخدام للطاقة دون رفع معدلات الاستهلاك.

يقدم الفصل الثاني دراسة نظرية للأداء الحراري لغلاف المبنى. الأداء الحراري هو صياغة نقل الطاقة بين البيئات الداخلية والخارجية، حيث انه له تأثير كبير على استهلاك الطاقة في المباني. يحتوي كل مبنى على حالة توازن حراري اعتمادًا على خمسة أعمدة تشكل حالة التوازن. يمكن تصنيف الأعمدة الخمسة على أنها قيمة النقل الحراري للغلاف ، ومعدل نقل الحرارة عبر التهوية ، واكتساب الحرارة الشمسية للمبنى ، واكتساب الحرارة الداخلية للمبنى ، وفقدان الحرارة. تمكنت الكائنات في الطبيعة من صياغة قدراتها من أجل الوصول إلى حالة التوازن الحراري الضرورية للبقاء في الظروف البيئية القاسية. ان دراسة وفهم تنظيم الحرارة في الطبيعة عن طريق استراتيجيات الكائنات الحية أدت إلى إيجاد حلول مبتكرة لبناء التحكم في الأداء الحراري لتحقيق معدلات الراحة الحرارية، حيث يعتمد إلهام استراتيجيات الطبيعة على الفكرة الرئيسية لتأثير البيوفيليا بين الإنسان والطبيعة.

يقدم الفصل الثالث دراسة نظرية للمحاكاة الحيوية في العمارة. المحاكاة الحيوية هي عملية تقليد استراتيجية الكائن الطبيعي من أجل الاستفادة من مشكلة مماثلة تمكن من حلها في الحياة الطبيعية. يعتبر التقليد الحيوي أهم مصدر إلهام للحلول المبتكرة الجديدة للمصممين للتغلب على الظروف البيئية المختلفة والتحكم فيها وتعزيزها. يمكن استخدام المحاكاة الحيوية من خلال اتجاهين هما اتجاه التصميم الذي يتطلع إلى علم الأحياء واتجاه علم الأحياء المؤثر على التصميم. يمكن استلهام تطبيق المحاكاة الحيوية من كل من أشكال تكوين الكائنات الطبيعية ، وأشكال الهياكل في الطبيعة والمواد المملوكة للكائنات الطبيعية. كل تطبيق من تطبيقات المحاكاة الحيوية يقودها مستوى محاكاة يساعد في صياغة عملية المحاكاة الحيوية بأكملها. يتم تصنيف مستويات المحاكاة الحيوية إلى ثلاثة مستويات رئيسية هي مستوى الكائن الحي ومستوى السلوك ومستوى النظام البيئي. من اجل تطبيق عملية ناجحة للمحاكاة الحيوية لتحسين الأداء الحراري لغلاف المبنى فانه يجب اختيار اتجاه المحاكاة الحيوية والتطبيق والمستوى المناسبين. يمكن أن يساعد النموذج الرقمي لتصميم غلاف المبنى في التحكم وفحص الأداء الحراري لغلاف المبنى المستوحى من الطبيعة.

يقدم الفصل الرابع دراسة تحليلية لخوارزميات تعزيز مثالية المحاكاة الحيوية. تم استخدام الخوارزميات في التصميم الرقمي في عصر المعلومات الرقمية نظرًا لقدرتها على إنتاج المنتج النهائي والتحكم فيه وتغييره بسهولة. يمكن إنتاج عدد لا نهائي من الأجيال من خلال تكوين خوارزمية واحدة وبسيطة مما يمد المصممين بعدد هائل من المفاهيم والأفكار المعقدة.

ملخص الرسالة

يعد غلاف المبنى خط الدفاع الأول للبيئة الداخلية في المواجهة الحتمية مع البيئة الخارجية، وتعد وظيفة المبنى وخصـــائصـــه وتأثيراته على المباني المحيطة به من العوامل الرئيســية المســتخدمة في تعريف غلاف المبنى حيث تتمثل الوظائف الأســاســية والرئيســية لغلاف المبنى في توفير الأمن والمأوى. يساعد غلاف المبنى في تحقيق معدلات الراحة داخل البيئة المبنية من خلال تحقيق افضـل معدلات ممكنة لكل من ضـوء النهار والحرارة والصـوتيات والطاقة الشمسية وجودة الهواء الداخلي ومقاومة الحريق والتحكم في الرطوبة. يعمل غلاف المبنى كركيزة أساسية لتحقيق الراحة الحرارية لجودة البيئة الداخلية للمباني.، ويساهم ايضا غلاف المبنى في توفير بيئة جمالية للمبنى من الداخل والخارج.

يعد الأداء الحراري أحد أهم العوامل التي لها تأثير كبير على استهلاك الطاقة فى المباني، حيث يمكن للمهندسين المعماريين باستخدام التنبؤ وحساب الأداء الحراري للمباني ان يتم تعزيز وتحسين ظروف البيئة الداخلية للمبانى باستخدام الحسابات التقديرية لمجموع الاحمال الحرارية المكتسبة لكل من التدفئة والتبريد .على صعيد اخر يتم استخدام الخوارزميات في الهندسة المعمارية لتوليد أشكال مستوحاة من الطبيعة يمكن أن تؤثر على الأداء الحراري. يقوم البحث على استخدام منهجية التصميم المعماري المبنية على إطار "النمذجة - المحاكاة - التحسين" للتحكم في الأداء الحراري لغلاف المبنى، حيث تم تحسين تصميم غلاف المبنى المعماري بواسطة خوارزميات المحاكاة الحيوية مثل الخوارزميات الجينية لتقليل الأداء الحراري. يستكشف البحث إمكانيات تحسين الأداء الحراري لغلاف المبنى عن طريق تقليل الأحمال الحرارية الإجمالية للوحدة المقترحة في مبنى المكاتب. توضح نتائج البحث أن دراسات الحالة المختلفة للأحمال الحرارية الإجمالية في مواقع مختلفة في العالم قد انخفضت عند مقارنتها بالحالة الافتراضية قبل عملية التحسين. تم تقديم التكوينات المحتملة لغلاف المبنى لتحسين الأداء الحراري في التصميم المعماري فى نهاية البحث.

الكلمات المفتاحية: الاداء الحرارى، غلاف المبنى، المحاكاة البيولوجية، الاستلهام من الطبيعة، تحسين الاداء، الخوارزميات الجينية

تعريف بمقدم الرسالة

الاسم	:	وائل صلاح منصور عبد الرحمن.
تاريخ الميلاد	:	25 مارس 1985.
محل الميلاد	:	القاهرة
اخر درجة جامعية	:	ماجستير العلوم.
مجال التخصص	:	الهندسة المعمارية.
الجهة المانحة	:	كلية الهندسة، جامعة عين شمس.
تاريخ المنح	:	2013.
الوظيفه الحالية	:	مدرس مساعد بقسم الهندسة المعمارية، كلية الهندسة بشبرا، جامعة بنها.

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قسم الهندسة المعمارية
الدراســـات العليـــــا

	التخصص: الهندسة المعمارية **القسم:** العمارة
	الدرجة: دكتوراة الفلسفة فى الهندسة
	اسم الباحث: وائل صلاح منصور عبد الرحمن
	تاريخ الميلاد: 25 مارس 1985
	البكالوريوس: يونيو 2007 - قسم العمارة - كلية الهندسة بشبرا - جامعة بنها
	الماجستير: مايو 2013 - قسم العمارة - كلية الهندسة - جامعة عين شمس
قسم العمارة – كلية الهندسة – جامعة عين شمس	تاريخ منح درجة الدكتوراة: / /
لجنة الفحص: أ.د. محمد خيرى امين أ.د. مراد عبد القادرعبد المحسن أ.د/ احمد عاطف الدسوقى أ.م.د/ اشرف على ابراهيم نسيم	**هيئة الاشراف:** أ.د/ احمد عاطف الدسوقى أ.م.د/ اشرف على ابراهيم نسيم
Thesis Title: Enhancing Thermal performance Of Building Envelope using Biomimetic optimization algorithms	**عنوان الرسالة:** تحسين الاداء الحرارى لغلاف المبنى باستخدام الخوارزميات لتعزيز المحاكاة البيولوجية
The research aims to enhance the thermal performance of the building envelope using biomimetic algorithms such as genetic algorithms so it investigates an architectural design Methodology based mainly on a “Modeling–Simulation–Optimization” framework. It explores the possibilities of enhancing the thermal performance of the building envelope by reducing the total thermal loads of a proposed unit in an office building. Results demonstrate that the total thermal loads different case studies in different locations in the world are decreased when compared with the default state before the optimization process. Finally, possible configurations of the building envelope are presented to enhance thermal performance in real architectural design.	يهدف البحث الى تحسين تصميم غلاف المبنى المعماري بواسطة خوارزميات المحاكاة الحيوية مثل الخوارزميات الجينية لتقليل الأداء الحراري حيث يقوم البحث على استخدام منهجية التصميم المعماري المبنية على إطار "النمذجة - المحاكاة - التحسين" للتحكم في الأداء الحراري لغلاف المبنى. يستكشف البحث إمكانيات تحسين الأداء الحراري لغلاف المبنى عن طريق تقليل الأحمال الحرارية الإجمالية للوحدة المقترحة في مبنى المكاتب. توضح نتائج البحث أن دراسات الحالة المختلفة للأحمال الحرارية الإجمالية في مواقع مختلفة في العالم قد انخفضت عند مقارنتها بالحالة الافتراضية قبل عملية التحسين. أخيرًا ، يتم تقديم التكوينات المحتملة لغلاف المبنى لتحسين الأداء الحراري في التصميم المعماري الحقيقي.

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قسم الهندسة المعمارية

تحسين الاداء الحرارى لغلاف المبنى باستخدام الخوارزميات لتعزيز المحاكاة البيولوجية

رسالة بحثية مقدمة كجزء من
متطلبات التقديم للحصول على درجة الدكتوراة في الفلسفة فى الهندسة المعمارية

مقدم من

وائل صلاح منصور عبد الرحمن
مدرس مساعد بقسم العمارة – كلية الهندسة بشبرا
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القاهرة، 2021.