GU J Sci, Part B, 7(3): 413-425 (2019)

Gazi University

Journal of Science

PART B: ART, HUMANITIES, DESIGN AND PLANNING

http://dergipark.gov.tr/gujsb

USING PARAMETRIC ALGORITHMS WITHIN THE CONTEXT OF ENERGY OPTIMIZATION OF BUILDING SKINS

Feyza Nur AKSİN [1]

Semra ARSLAN SELÇUK[1]

[1]*Gazi University, Faculty of Architecture, Department of Architecture, Maltepe / Ankara. TURKEY*

Article Info

Received: 16/09/2019
Accepted: 30/09/2019

Keywords

Parametric algorithms,
Computational architecture,
Performance based design,
Energy optimization,
Building skins

Abstract

As a result of the continuous increase in the need for energy, the construction industry focuses more on energy efficient buildings and systems. In this process, the concept of "performance" can be considered as the key issue behind the design's decisions. From this context, the purpose of this study is to investigate how parametric modeling techniques and algorithms can be used together with to optimize building energy performance. The study is conducted through descriptive method and case study analysis covering recently designed four pioneering examples. Consequently, design samples were examined and evaluated within the framework of energy optimization on the building skin.

1. INTRODUCTION

The energy consumption in the world shows continuous growth annually and increases the emission amount of many greenhouse gases in the environment, especially carbon dioxide (Fig. 1). The increasing amount of carbon dioxide in the atmosphere causes intense climate changes, global warming and various diseases, destroying the environment and human health [22].

Today, energy consumption in the construction sector is around 20% to 40% of global energy consumption. As the world population continues to grow and societies begin to spend more time in the interiors, the demand for building services also increases and the continuous operation of these systems, especially the HVAC, in the daily cycle, contributes significantly to the energy consumption [44].

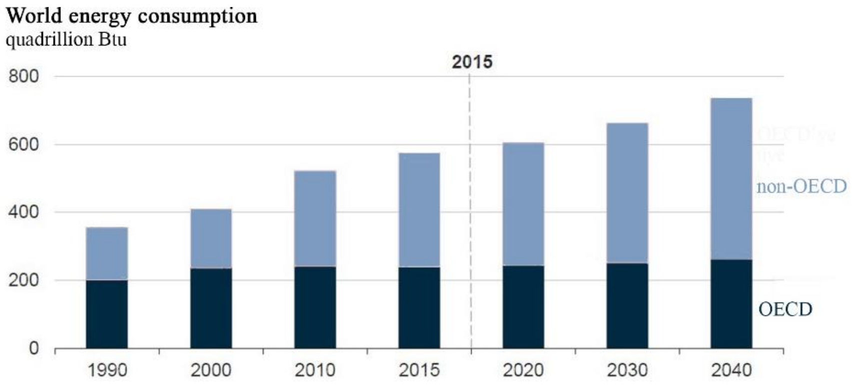


Figure 1. World energy consumption, [10]

---

* Corresponding author: feyzanuraksin@gmail.com

With increasing energy needs and increased consumption of resources, the construction industry focuses on innovative designs with high energy efficiency. The concept of performance has come to the forefront with the orientation to sustainable design and energy efficient buildings, and designers plunged into new quests because the traditional design methods are inadequate in evaluating the energy performance of buildings and restricting them. Nowadays, with the emergence of parametric design software tools and optimization algorithms widely used in architecture, a wide range of design areas has emerged and various performance data for buildings has become measurable and optimized.

In this context, at this study, it has been investigated how parametric modeling techniques and algorithms are combined in order to optimize building energy performance and it is aimed to question the hypothesis that by using parametric based algorithm a novel building energy performance optimization process can be developed for building skins.

While in the second part of the study, which started with the introduction section, the building skin and energy efficiency were discussed, in the third section, various subjects were examined under the title of energy efficient environments and performative architecture and the study was completed with the conclusion section.

2. BUILDING SKIN AND ENERGY EFFICIENCY

Recent researches and studies show that between 10% and 30% of the energy use in buildings can be reduced together with the existing and cost effective equipment and technology. It is thought that this ratio will be doubled if various interdisciplinary research ideas and results can be applied to real buildings [22].

When the amount of energy used in the life cycle of buildings is analyzed, it is seen that the most difficult and highest consumption rate is the amount of energy consumed by the users to optimize the comfort conditions when the building is opened for use [34: 18]. The building skin, one of the most important components of the building, which directly affects the user comfort and evaluates the buildings in terms of energy efficiency, affects the dynamics of the building to a great extent while separating the interior from the external environment. As can be seen in Figure 2, there is an intense interaction between the comfort conditions provided by the building skin and the energy.

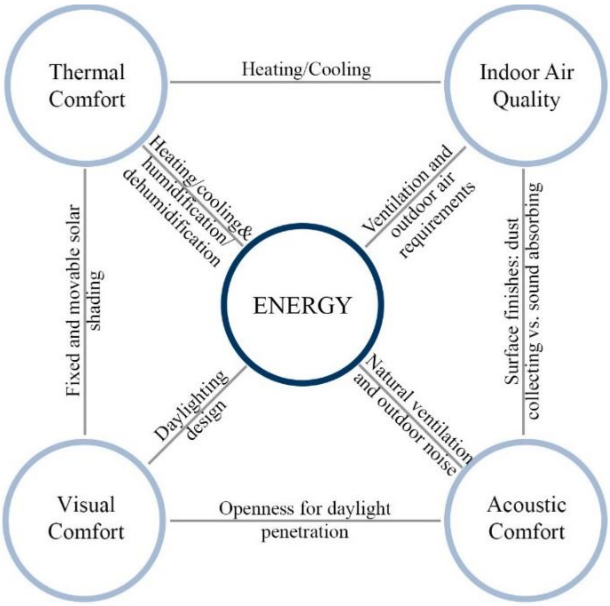


Figure 2. Interactions between forms of comfort and building energy use, [7]

While previously building skins providing shelter, protection and structure services, the roles undertaken by the building skins increased and went beyond the shelter and became a component regulating indoor climate comfort. The building skin serves as a climatic comfort regulator and controls the flow of factors, such as thermal and solar radiation, humidity, air, with various components like exterior walls, floors, windows, doors, roofs [13; 21]. Since building skin components are sensitive to sunlight and other environmental changes and therefore directly affect indoor conditions and user comfort, they play a very important role in the protection of the space and thus in the protection of energy [16: 70-71; 39]

2.1. Energy Efficient Building Skins

Nowadays, development of mechanical systems reduced the building's dependence of natural ventilation and lighting. Technical solutions such as artificial lighting, heating and cooling, which are considered necessary to maintain the comfort of the interior space and cause a high energy consumption, has created a great disconnection between natural ecology and man-made ecology created in the interior [24]. Figure 3, showing the relationship between energy use and building skin, points that with the use of improved building skin, the dependence on HVAC systems is reduced and the user comfort is increased.

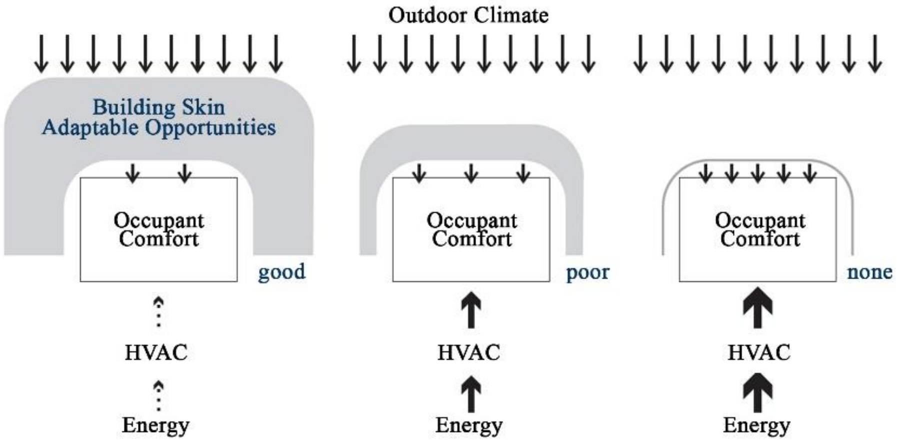


Figure 3. The relationship between energy use and building skin, [13]

In order to reduce building energy consumption and environmental damage, building skin performance is very important in design. With the necessary care of the designers, building skin while reduces energy costs due to outdoor climate conditions, can maximizes user comfort determined by factors such as thermal comfort, air quality, daylight, humidity, acoustic and security [13].

In this context, the next part of the paper focuses on the interaction of the building skin with the sun which is one of the most important parameters in determining the user comfort in the interior environment and forms the outdoor conditions.

2.2. Effects of Solar Energy on Building Skins

The Sun has been used as a useful energy source for many years, from the time of human existence to the present [45: 1]. Considering the energy consumption in buildings, loads that contribute heavily to consumption, such as heating, cooling and lighting, are directly related to solar energy. In order to control heat gain which is caused from daylight, in the design, the balances between daylight performance parameters should be ensured properly and the design process should be developed in this way.

A successful daylight design, as El Sheikh [11] points out, is not related to increasing the dimensions of the openings in the building skin, but rather to ensure the correct alignment of factors such as glare, heat gain, change in existing light level, direct penetration of light. In his book Sunlighting as Formgiver for Architecture, Lam [25: 4] mentions that general design goals can be applied to daylight design and performance, such as providing comfort in the interior environment, meeting programmatic needs, minimizing building energy costs, minimizing building construction costs. In order to evaluate the daylight performance in buildings, daylight quantity, daylight quality and visual comfort, thermal comfort, daylight related energy efficiency should be examined in detail.

The first objective in daylight design is to provide sufficient natural light according to the needs of the designed space [17]. The quality of daylight-related illumination is determined by creating appropriate conditions for the visual action, supporting work efficiency, promoting communication and interaction, improving the health conditions for users and creating the aesthetic position of the space [11]. According to Veitch [43], the quality of the lighting can be determined by establishing the balance of the parameters shown in the diagram in Table 1. These parameters, as indicated in the table, are not only related to architecture, but also to personal comfort and cost.

Table 1. Qualities of lighting, [43]

LIGHTING QUALITY		
INDIVIDUAL WELL-BEING	ECONOMICS	ARCHITECTURE
visibility activity social & communication comfort health & safety	form composition style codes & standards	installation maintenance operation energy environment

Another factor that determines daylight performance is thermal comfort. As cited by Carlucci et al. [7] while thermal comfort is generally used to describe situations in which the users do not feel too hot or too cold in the provided thermal environment, by many scientists and doctors, this situation is determined by three factors: physiological, psychological and also rational approach, which is an approach based on the heat balance of the human body. The performance of thermal comfort in buildings is a serious problem because it consumes a large part of the building energy to meet the comfort requirements [2]. Various studies have shown that daylight and lighting controls will reduce the primary energy consumption of the building with successful and adequate use within the design [6; 20; 23; 26].

3. ENERGY EFFICIENT ENVIRONMENTS AND PERFORMATIVE ARCHITECTURE

An innovative design method and an integrated design process are needed to meet the requirements of building design with low energy consumption. At this point, digital modeling and computational technologies have greatly influenced the architectural design field. The use of parameters and algorithms in the architectural design process leads designers to re-evaluate the system of rules used in the architectural production process. In this way, in contrast to the classical databases, a new type of architecture database that contains form production tools and methods based on computer codes is slowly evolving [18]. Peters and Peters [33: 3] states that, the history of computer aided design (CAD) is evaluated in three periods. These are two-dimensional drawing period, building information modeling (BIM) period and computational design period. The computational design period refers to a period in which the designer no longer makes a direct model but instead develops an algorithm and the algorithm which he develops produces the model.

3.1. Parametric Design

Building technologies today, as Eltaweel and Yuehong [12] points out, involve many disciplines at the same time, and each discipline is linked to other disciplines with complex links and therefore, a database container should be arranged and the container must be managed parametrically by using the parametric design. As highlighted by Hernandez [19] parametric design has a design process that takes place in an environment where variations are infinite, and thus the singularity and the multiplicity are displaced in the design process.

Parametric modeling, with the use of parametric rules between objects, makes it possible to create a productive form based on aesthetics and performance parameters of the building, and to automatically update objects according to changes in context [1]. Today, the most prominent parametric modeling tools can be listed as Generative Component developed by Bentley Systems, Digital Project ™ which can be run with CATIA®, Grasshopper used with Rhinoceros and GraphiSoft ArchiCAD and Dynamo / Revit from Building Information Modeling (BIM) [46]. These softwares are also used for building performance analysis with various plug-ins, providing input data such as climatic data, building form, materials, the definition and operation of HVAC systems, and outputs such as energy consumption, thermal and visual comfort and daylight measurements [14].

3.2. Using Algorithms in Design and Optimization

In general situation of architectural design, computing power and algorithms provided by computers are used for the production and performance-based designs of architectural forms that can be presented as very complex and computational [3]. Algorithms can generate and use design inputs such as geometric form, design variables, mathematical expressions and operations. Having this level of control over the design allows designers to expand functionality, evaluate certain conditions and respond accordingly [9].

Architectural design is a complex decision-making process and a targeted activity. At the same time, architectural design can be seen as a multi-purpose optimization process that seeks to find the ideal solutions for multiple targets [36; as cited in 42]. Access to these objectives in the design process is generally achieved by the correct combination of building simulation programs and appropriate optimization algorithms [40]. Wetter [47] collected the algorithms used in optimization as in fig. 4 [as cited in 37].

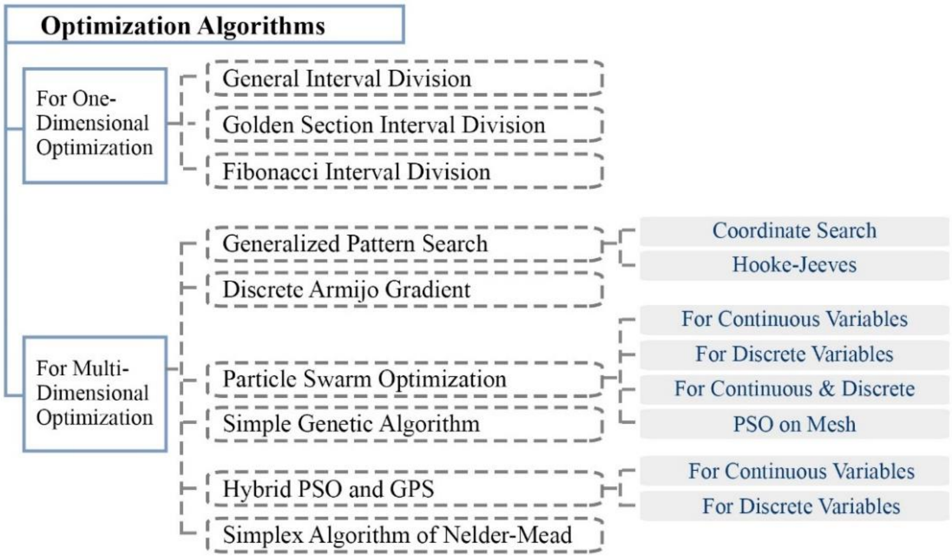


Figure 4. Optimization algorithms [47; as cited in 37]

Rahman [37] stated that to make the right choice from optimization algorithms depends on issues such as structure of function, availability of analytical primary and secondary derivatives, the size of the problem and the problem’s constraints.

Building design optimization studies have recently been used to calculate building environmental performance. As a result, optimization based on simulation and algorithms has been transformed into an efficient process to meet the requirements of energy-efficient buildings [30].

3.3. Performative Architecture/Performance Based Design

The concept of performance is intertwined with architecture as a lasting thought in architectural discourse. In recent years, the discipline of architecture has intensified on this concept because of its potential contribution to the current problems in the built environment design [29: 4]. In the construction sector, with the increasing demand for energy efficient buildings, the energy performance of the building is becoming an important force behind design decisions. It is now expected from the designers that they make designs with more efficient for energy saving and where energy performance is considered with the discovery of design alternatives [28].

The basic requirement for high performance building design is that it works as an integrated energy system that creates a good indoor environment suitable for the building's functions [4: 3]. While performance-based design refers to a design process that covers an emphasis or individual design goal that focuses on improved performance [27], it requires designers to explore the potential design alternatives parametrically and choose the best alternative for the project [38].

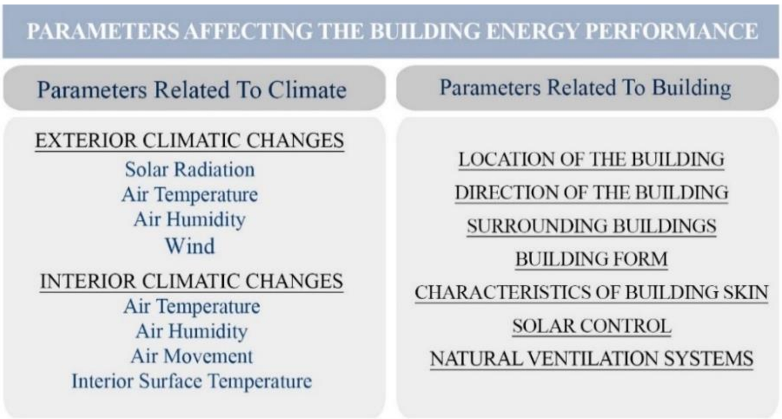
Chronis, Liapi, and Sibetheros [8] sorted the main steps of the process aimed at optimizing the environmental performance of the building as:

- to conduct a climate analysis and to develop a digital database of local climatic features,
- to develop a parametric model linking climatic analysis databases and building geometry,
- to explore the geometry of the building and develop an algorithm to use the parametric model.

3.4. Building Energy Performance Optimization

Energy performance optimization in buildings compared to typical buildings; usually saves energy costs between 30% and 50% [15]. Although applying energy efficient design strategies to buildings individually supports the energy performance of the building to a certain extent, in order to achieve a high level of energy performance, the parameters affecting the building performance shown in table 2 should be evaluated and various strategies should be combined and used together [41].

Table 2. Parameters affecting the building energy performance [31]



PARAMETERS AFFECTING THE BUILDING ENERGY PERFORMANCE

Parameters Related To Climate	Parameters Related To Building
EXTERIOR CLIMATIC CHANGES	LOCATION OF THE BUILDING
Solar Radiation	DIRECTION OF THE BUILDING
Air Temperature	SURROUNDING BUILDINGS
Air Humidity	BUILDING FORM
Wind	CHARACTERISTICS OF BUILDING SKIN
INTERIOR CLIMATIC CHANGES	SOLAR CONTROL
Air Temperature	NATURAL VENTILATION SYSTEMS
Air Humidity	
Air Movement	
Interior Surface Temperature	

Nguyen, Reiter and Rigo [30], summarized the tendency to use optimization algorithms in their literature review research, which is related to the application of simulation-based optimization methods to building performance analysis, as in fig. 5.

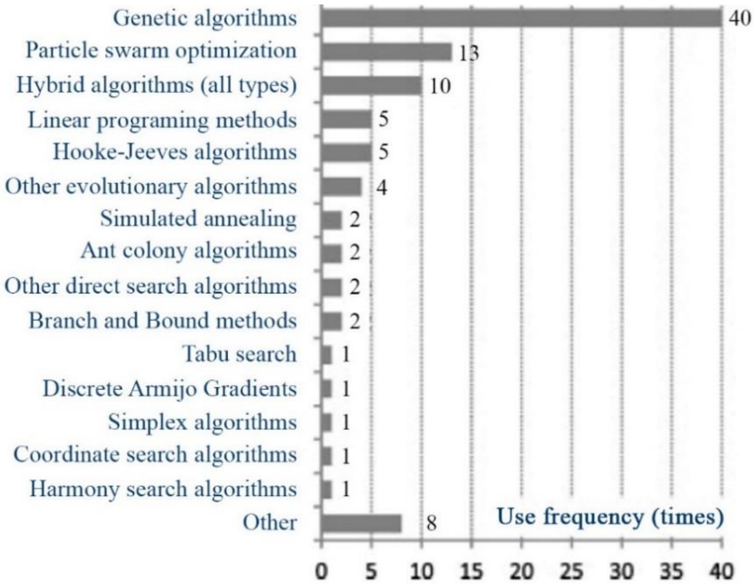


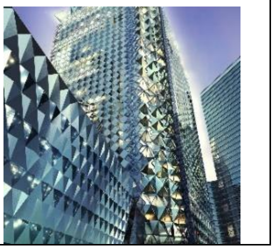
Figure 5. Use frequency of different optimization algorithms, [30]

Attia, Hamdy, O'Brien, and Carlucci [5], divided building performance optimization tools into two categories as independent optimization tools and simulation-based optimization tools and while gave such examples for independent optimization tools as MATLAB Toolbox, GenOpt, ThermalOpt, Topgui, ParadisEO, gave examples for simulation-based optimization tools such as TRNOpt, BeOpt, Opt-Plus, GENE_ARCH, ParaGen. Nguyen et al. [30] gave examples for optimization programs that can be used in building performance optimization some softwares like BeOpt, GENE_ARCH, GenOpt, jEPlus, MATLAB Toolbox, MultiOpt 2, Opt-E-Plus, ParadisEO, TRNOpt. These tools focus on various aspects of building performance such as building energy efficiency and consumption, thermal comfort, ventilation and indoor air quality, lighting, acoustics.

3.5. The Use of Parametric and Performance Based Design on Building Skins

In this part of the study, how the optimization of building energy performance has been implemented in contemporary architectural designs is examined. Selected designs; Samba Headquarters, Hanwha Headquarters Remodelling, Grove Towers and Nanjing International Youth Cultural Centre were evaluated with reference to the building skin. The reason for selecting these four examples is that they are common in their usage of innovative and compuational methods for energy optimization in the building skin. While the construction of Samba Headquarters, Hanwha Headquarters Remodeling and Nanjing International Youth Cultural Center buildings are completed, Grove Towers building is still under construction.

Samba Headquarters

Building ID	**Architect**	Foster+Partners	
	Location	Riyadh, Saudi Arabia	
	Function	Office	
	Construction Years	2011-2018	
	Area	92,000 m^2	
	Height	231.2 m	
	Facade and Sustainability Consultant	BuroHappold Engineering	

The design of the triangular glass panels in the skin provides an effective solution to the complex climate of Riyadh in winter with temperatures of zero and below and in summer with dry heat and occasional heavy rain. Each panel is made up of opaque canopy panels and two different types of high-performance reflective glass surfaces [49]. A parametric façade design tool (Figure 6) has been developed and used by

Burohappold to maximize the daylight factor in design and to optimize the solar and transmissive gains [32: 140].

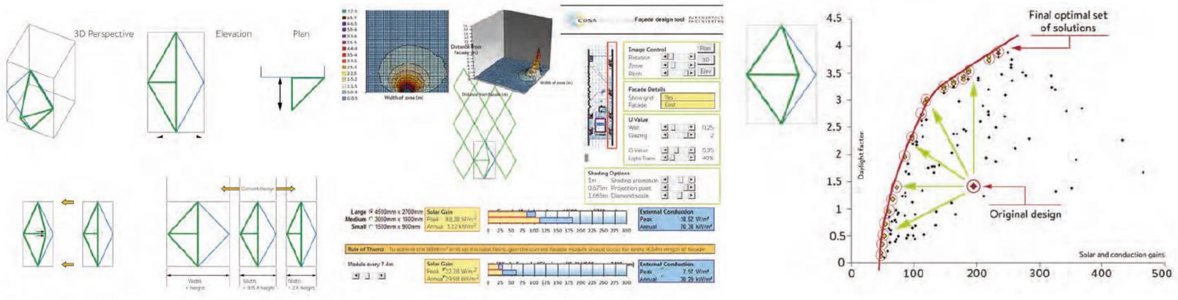
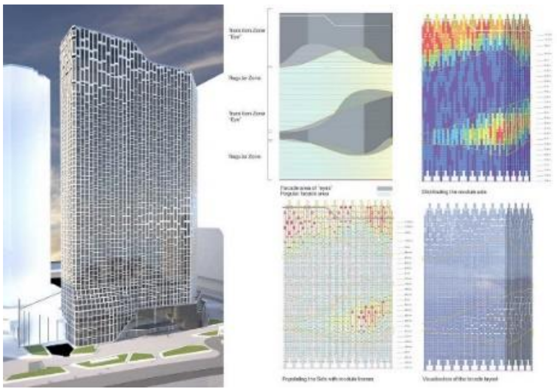


Figure 6. Parametric facade design tool and optimized skin design solutions graphic used for optimization, [32: 140]

Hanwha Headquarters Remodelling

Building ID			
	Architect	UNStudio	
	Location	Seoul, South Korea	
	Function	Office	
	Construction Years	2014-2018	
	Area	57,696 m²	
	Height	124 m	
	Facade and Sustainability Consultant	ARUP Hong Kong	

The modules in each facade are located differently (Figure 7) to the environmental factors. For example, while the northern façade is shaped to take more daylight into the building, the southern façade is made more opaque to reduce the heat load on the building. While the direct sunshine is reduced by the shading provided by the angled placement of the windows in some parts of the facade, the windows in the upper part of the southern façade are placed at an angle to receive direct sunlight [52]. 80% of the main facade consists of main modules. The remaining 20% slice was obtained with minor changes on the main modules, as seen in Figure 8. Since there are many module variations, a unit-making tool has been developed in order to generate these variations automatically with the parameters present [51].



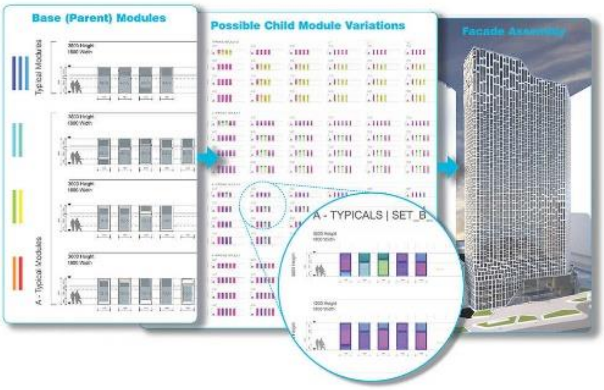


Figure 7. Creation of a design model, [50], Figure 8. Main and sub modules, [51]

Grove Towers

Building ID	**Architect**	3XN	
	Location	Mumbai, India	
	Function	Mixed-Use	
	Construction Years	2014- (under construction)	
	Area	78,000 m^2	
	Height	130 m	
	Facade and Sustainability Consultant	BuroHappold Engineering	

The environmental performance of the building was analyzed on more than one scale and the building forms were optimized by using the data obtained from daylight. The façade works were advanced so that each window was at different sizes and angles (Figure 9) without obstructing the external view. The parametric and simulation-based workflow has resulted in many design options that reduce different levels of radiation [35: 133]. A large number of corners in the skin, providing natural cross ventilation, reduces the need for ventilation [48].

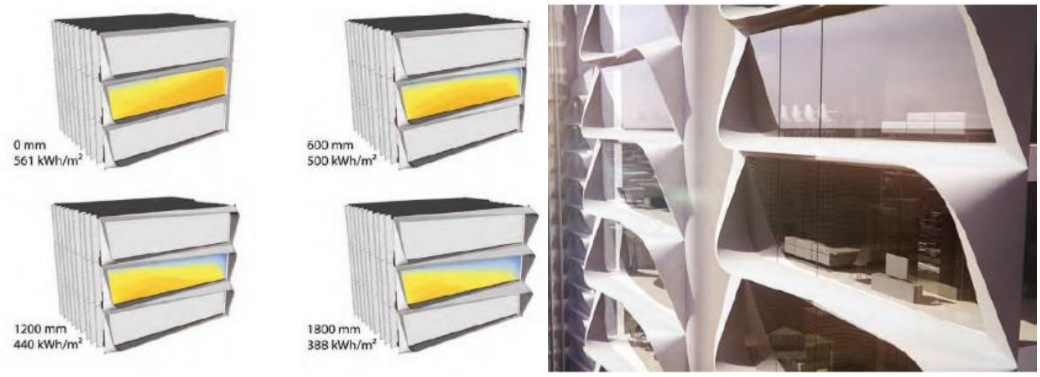


Figure 9. Grove Towers skin optimization in the context of daylight and energy [35: 132-133]

Nanjing International Youth Cultural Centre

Building ID	**Architect**	Zaha Hadid Architects	
	Location	Nanjing, Jiangsu, China	
	Function	Mixed-Use/Cultural Centre	
	Construction Years	2011-2018	
	Area	106,500 m^2	
	Height	45 m	
	Facade and Sustainability Consultant	BuroHappold Engineering	

Various passive design strategies have been used to maximize the sustainability of the project. Complex design details such as optimization of natural ventilation and lighting and the use of a self-cleaning façade system have been solved and elaborated with the parametrically managed design process. A special parametric façade design tool (Figure 10) was developed by Burohappold for optimization work and a variety of variations are found to be the best choices and energy efficiency is maximized [33: 146].

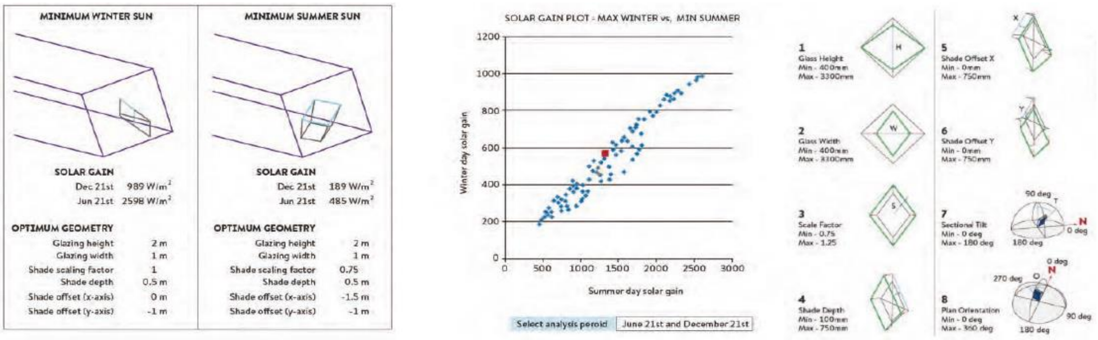


Figure 10. Parametric skin design tool developed for Nanjing International Youth Culture Center by Burohappold, [33: 146]

As a result of the research and literature review conducted during the study, eight parameters were determined for energy optimization in the building skin and the design samples examined in this section were evaluated over the determined parameters at table 3.

Table 3. The use of parametric algorithms for energy optimization in building skin

	Selected Contemporary Architectural Designs			
	Samba Headquarters	**Hanwha Headquarters Remodelling**	**Grove Towers**	**Nanjing International Youth Cultural Centre**
Accepting the solar effect on the building skin as an input to the design	+	+	+	+
Use of parametric design / Simulation-based workflow	+	+	+	+
Calculation of the possible energy performance of the design	+	+	+	+
Evaluation of energy gains and losses associated with the building skin	+	+	+	+
Development of innovative optimization tool specific to energy efficiency of building skin	+	+	+	+
Use of algorithms to solve complex design problems	+	+	+	+
Realization of energy optimization	+	+	+	+
Energy efficient/Performative skin design	+	+	+	+

4. CONSLUSION

As a result, it can be seen that increasing energy consumption rates bring about environmental problems. It is thought that the rapid depletion of resources and the irreversible damage to the environment will cause many problems in the near future. Considering that the construction industry has a large share in this consumption, innovative design solutions within the industry are gaining importance in order to minimize energy consumption and environmental damage.

Today, various simulation programs and optimization tools are used to calculate the environmental impact and energy performance of buildings. Using energy-efficient parametric designs, which integrate algorithms with energy simulation and optimization tools, presents various design alternatives and allows for the simultaneous evaluation of many parameters. As for the building skin, it is one of the most important components of the building in the evaluation of energy efficiency.

In this study, in order to make an evaluation in this context; various subjects are discussed in terms of energy optimization of building skins and usage of computational methods and examples of their use in contemporary architectural designs are examined. When examining selected designs, it has become clear that the evaluation of performative architecture and computational technologies in design reduces energy consumption and promotes more efficient skin production.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors

5. REFERENCES

[1] Aish, R., & Woodbury, R. (2005). Multi-level Interaction in Parametric Design. Paper presented at the International Symposium on Smart Graphics.

[2] Al-Din, S. S. M., Iranfare, M., & Surchi, Z. N. S. (2017). Building Thermal Comfort Based on Envelope Development: Criteria for selecting right case study in Kyrenia-North Cyprus. Energy Procedia, 115, 80-91.

[3] Almusharaf, A. M. (2011). Incorporating The Structure of Tall Buildings Within An Architectural Form Generation Process. (Doctor of Philosophy), Illinois Institute of Technology,

[4] Athienitis, A., & O'Brien, W. (2015). Modeling, Design, and Optimization of Net-Zero Energy Buildings: John Wiley & Sons.

[5] Attia, S., Hamdy, M., O’Brien, W., & Carlucci, S. (2013). Assessing Gaps and Needs for Integrating Building Performance Optimization Tools in Net Zero Energy Buildings Design. Energy Buildings, 60, 110-124.

[6] Bodart, M., & De Herde, A. (2002). Global Energy Savings in Offices Buildings by The Use of Daylighting. Energy Buildings, 34(5), 421-429.

[7] Carlucci, S., Pagliano, L., O’Brien, W., & Kapsis, K. (2015). Comfort Considerations in Net ZEBs: Theory and Design. In A. Athienitis & W. O'Brien (Eds.), Modeling, Design, and Optimization of Net-Zero Energy Buildings (pp. 75-106): John Wiley & Sons.

[8] Chronis, A., Liapi, K. A., & Sibetheros, I. (2012). A Parametric Approach to the Bioclimatic Design of Large Scale Projects: The Case of a Student Housing Complex. Automation in Construction, 22, 24-35.

[9] Dino, I. (2012). Creative Design Exploration by Parametric Generative Systems in Architecture. METU Journal of Faculty of Architecture, 29(1), 207-224.

[10] EIA. (2017). International Energy Outlook 2017. Retrieved from www.eia.gov/ieo

[11] El Sheikh, M. M. (2011). Intelligent Building Skins: Parametric-Based Algorithm For Kinetic Facades Design And Daylighting Performance Integration. (Master of Building Science), University of Southern California,

[12] Eltaweel, A. & Yuehong, S. (2017). Parametric Design and Daylighting: A Literature Review. Renewable Sustainable Energy Reviews, 73, 1086-1103.

[13] Erickson, J. (2013). Envelope As Climate Negotiator: Evaluating Adaptive Building Envelope's Capacity To Moderate Indoor Climate And Energy. (Doctor of Philosophy), Arizona State University,

[14] Fang, Y. (2017). Optimization of Daylighting and Energy Performance Using Parametric Design, Simulation Modeling, and Genetic Algorithms. (Ph.D. in Design), North Carolina State University,

[15] Farias, F. (2013). Contemporary Strategies for Sustainable Design. (Doctor of Philosophy), Texas A&M University,

[16] Friedman, A. (2012). Fundamentals of Sustainable Dwellings: Island Press.

[17] Ghobad, L. (2013). Analysis of Daylighting Performance and Energy Savings in Roof Daylighting Systems. (Doctor of Philosophy), North Carolina State University,

[18] Grobman, Y. (2013). The Various Dimensions of the Concept of 'Performance'in Architecture. In Y. J. Grobman & E. Neuman (Eds.), Performalism: Form and Performance in Digital Architecture (pp. 9-13): Routledge.

[19] Hernandez, C. R. B. (2006). Thinking Parametric Design: Introducing Parametric Gaudi. Design Studies, 27(3), 309-324.

[20] Ihm, P., Nemri, A., & Krarti, M. (2009). Estimation of Lighting Energy Savings From Daylighting. Building Environment, 44(3), 509-514.

[21] John, G., Clements-Croome, D., & Jeronimidis, G. (2005). Sustainable Building Solutions: A Review of Lessons from The Natural World. Building Environment, 40(3), 319-328.

[22] Karizi, N. (2015). An Adaptive Intelligent Integrated Lighting Control Approach for High-Performance Office Buildings. (Doctor of Philosophy), Arizona State University,

[23] Kolokotroni, M., Robinson-Gayle, S., Tanno, S., & Cripps, A. (2004). Environmental Impact Analysis for Typical Office Facades. Building Research Information, 32(1), 2-16.

[24] Krietemeyer, E. A. (2013). Dynamic design framework for mediated bioresponsive building envelopes. (Doctor of Philosophy), Rensselaer Polytechnic Institute,

[25] Lam, W. M. (1985). Sunlighting as Formgiver for Architecture: Van Nostrand Reinhold.

[26] Li, D. H., & Lam, J. C. (2003). An Investigation of Daylighting Performance and Energy Saving in A Daylit Corridor. Energy Buildings, 35(4), 365-373.

[27] Lin, S.-H. E. (2014). Designing-In Performance: Energy Simulation Feedback For Early Stage Design Decision Making. (Doctor of Philosophy), University of Southern California,

[28] Malkawi, A. M. (2004). Developments in Environmental Performance Simulation. Automation in Construction, 13(4), 437-445.

[29] Ng, R. (2013). Introduction: Experimental Performances: Materials as Actors. In R. Ng & S. Patel (Eds.), Performative Materials in Architecture and Design (pp. 1-18): Intellect.

[30] Nguyen, A.-T., Reiter, S., & Rigo, P. (2014). A Review on Simulation-Based Optimization Methods Applied to Building Performance Analysis. Applied Energy, 113, 1043-1058.

[31] Ozdemir, B. (2005). Sürdürülebilir Çevre İçin Binaların Enerji Etkin Pasif Sistemler Olarak Tasarlanması (Master Thesis), ITU, İstanbul.

[32] Peters, B. (2018). Bespoke Tools for a Better World: The Art of Sustainable Design at Burohappold Engineering. In B. Peters & T. Peters (Eds.), Computing the Environment: Digital Design Tools for Simulation and Visualisation of Sustainable Architecture (pp. 138-149): John Wiley & Sons.

[33] Peters, B., & Peters, T. (2018). Introduction. In B. Peters & T. Peters (Eds.), Computing the Environment: Digital Design Tools for Simulation and Visualisation of Sustainable Architecture (pp. 1-13): John Wiley & Sons.

[34] Peters, T. (2018a). New Dialogues About Energy: Performance, Carbon and Climate. In B. Peters & T. Peters (Eds.), Computing the Environment: Digital Design Tools for Simulation and Visualisation of Sustainable Architecture (pp. 14-27): John Wiley & Sons.

[35] Peters, T. (2018b). Architecture Shapes Performance: GXN Advances Solar Modelling And Sensing. In B. Peters & T. Peters (Eds.), Computing the Environment: Digital Design Tools for Simulation and Visualisation of Sustainable Architecture (pp. 128-137): John Wiley & Sons.

[36] Radford, A. D., & Gero, J. S. (1987). Design by Optimization in Architecture, Building, and Construction: John Wiley & Sons, Inc.

[37] Rahman, A. (2014). Optimizing The Performance Of Building Envelope For Energy Efficiency Considering Adaptive Thermal Comfort: A Case Of Tropical Climate In Dhaka. (Doctor of Philosophy), Illinois Institute of Technology,

[38] Rahmani Asl, M. (2015). A Building Information Model (BIM) Based Framework for Performance Optimization. (Doctor of Philosophy), Texas A&M University,

[39] Sadineni, S. B., Madala, S., & Boehm, R. F. (2011). Passive Building Energy Savings: A Review of Building Envelope Components. Renewable Sustainable Energy Reviews, 15(8), 3617-3631.

[40] Shan, R. (2016). Climate Responsive Façade Optimization Strategy. (Doctor of Philosophy), The University of Michigan,

[41] Stevanović, S. (2013). Optimization of Passive Solar Design Strategies: A Review. Renewable Sustainable Energy Reviews, 25, 177-196.

[42] Su, Z. (2015). Improving Design Optimization and Optimization-based Design Knowledge Discovery. (Doctor of Philosophy), Texas A&M University,

[43] Veitch, J. A. (2001). Psychological Processes Influencing Lighting Quality. Journal of the Illuminating Engineering Society, 30(1), 124-140.

[44] Vong, N. (2016). Climate Change and Building Energy Use: Evaluating the Impact of Future Weather on Building Energy Performance in Tropical Regions. (Doctor of Architecture), University of Hawaii,

[45] Walker, A. (2013). Solar Energy: Technologies and Project Delivery for Buildings: John Wiley & Sons.

[46] Wang, T.-H. (2012). Customizing Pattern-Based Tessellation for NURBS Surface Reconstruction with Irregular Boundary Conditions. (Doctor of Philosophy), Carnegie Mellon University,

[47] Wetter, M. (2004). Simulation-Based Building Energy Optimization. (Doctor of Philosophy (Unpublished)), University of California, Berkeley.

[48] Internet: https://archello.com/project/grove-towers#stories , Access date: 28.08.2019

[49] Internet: https://www.fosterandpartners.com/projects/samba-headquarters/ , Access date: 25.08.2019

[50] Internet: https://www.unstudio.com/en/page/5879/study-hanwha-headquarters-responsive-facade-part-1 , Access date: 27.08.2019

[51] Internet: https://www.unstudio.com/en/page/5882/study-hanwha-headquarters-responsive-facade-part-2 , Access date: 27.08.2019

[52] Internet: https://www.unstudio.com/en/page/3405/hanwha-headquarters-remodelling , Access date: 26.08.2019