Methods to Discover the Optimum Building Envelope in the Context of Solar Data

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Highlights
• This paper focuses on the design methods for maximum efficiency.
• The pros and cons of the methods are determined by SWOT analysis.
• The energy efficient buildings can be designed by using methods for shading.

Article Info

Abstract

This study deals with present optimum building envelope design methods and designate the pros and cons in built environments while managing the solar parameters using the modern software that enables digital, performance-based design. Performance-based design process is detailed; designs based on sun rays with various methods are reviewed; and the relationship between building envelope and energy is specified. It is the objective of the study that determination of methods used to decide alternative forms to avoid excessive heat gains during the summer season while providing maximum benefit from the sun's rays during the winter season. Therefore, samples that can generate input are selected. Each sample is determined to belong to a different group of design methods and these methods are classified. As a result of the samples investigated, the advantages and disadvantages of the methods used in comparison with using the comparing method by figures and tables. Then, with the SWOT analysis method, the methods' strengths and weaknesses, opportunities and threats are identified. Accordingly, Method 3- The Solar Rays Method has a faster and easier design process than the other two methods. Shortly, it has the optimum solution in other design methods with is three potential factors and one problem. With these proposed methods, it is aimed to reach an optimum solution by considering the potential to creating shadows on the building.

1. INTRODUCTION

Turkey highly depends on outer sources for energy. Construction sector requires inexpensive high-quality solutions that use renewable energy sources more.

Modern technology provides solutions with digital data format supporting all stages of projects and working methods. Performance-based design is defined as the synthesis of two features, geometric formation with digital design and simulation-based performance evaluation [1]. In addition, 2013 AIA (American Institute of Architecture) Architecture 2030 Commitment Progress report indicates that energy modelling is used in 66% of projects. Energy performance is 8% higher in projects which initiated energy modelling [2]. Technology is used in modelling stage of design more than in planning stage, which suggests that the data that could be significant for design are not considered adequately.

Turkey has the potential of benefiting from solar energy more than European countries due to its geographical location (Figure 1) [3].

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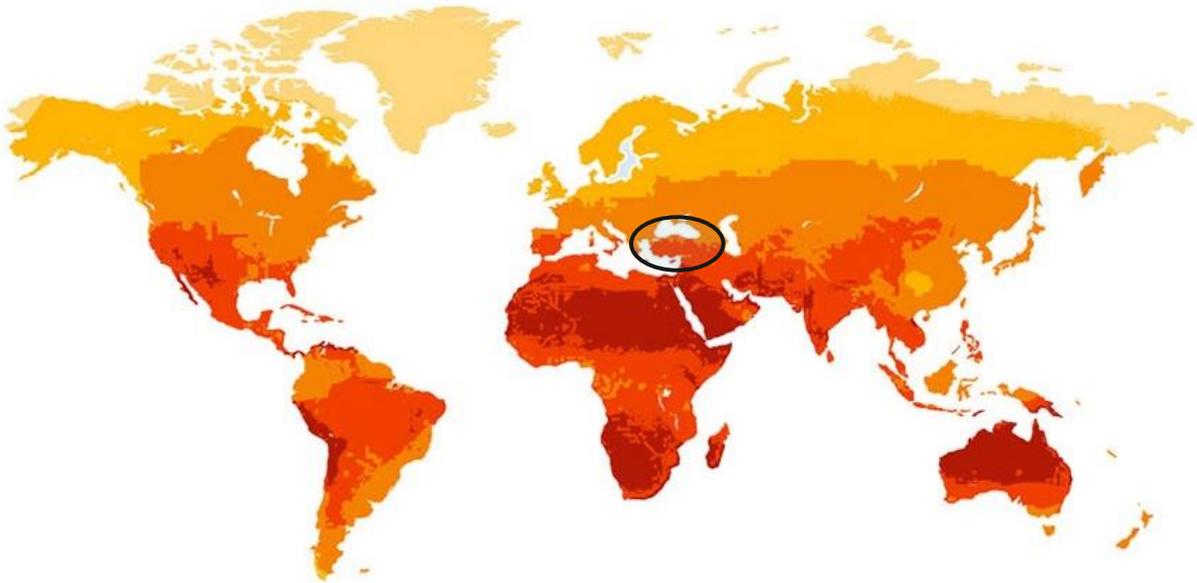
Figure 1. *Design processes based on structure and performance [3]*

85% of the energy used in buildings is for heating and cooling purposes [4]. In this study, the sun is chosen from the environmental conditions affecting the design of the building envelope as it benefits maximum from the sun's rays during the winter season, while preventing excessive heat gain during the summer season. In architecture, considering the importance of the design processes of the projects, performance-based design using algorithmic graphical programs offers a proposal that provides maximum benefit to the designer.

1.1. Problem

Energy efficiency is a major issue for developed countries, which created the obligation to conduct detailed studies and form criteria for performing energy-efficient designs. Thus, building envelopes that are formed considering the solar data should be considered as the first step to fulfil targets related to ecological environment.

Certain methods related to how building envelope should be for energy preservation are specified considering the incidence angle of solar rays. Collecting information about the usability and practicability of these methods and questioning the efficiency while determining the pros and cons constitute the basis of the problem.

1.2. Objective

Presenting optimum building envelope design methods in built environments by using solar parameters, which is the most effective environmental factor in Turkey, on modern software and designating the pros and cons and offering solution for any problem constitute the objective. The findings of this study will be instructive for using new design methods. Minimizing the energy loss, a significant step will be taken to achieve energy gain. Thus, energy efficiency will be achieved in construction sector, which will contribute greatly to the domestic economy.

1.3. Scope

The relationship between performance-based design, which includes solar-based building envelope designs as a significant part of the search for solutions related to energy issue, and digital design will be presented, and practicability will be questioned reviewing the building samples design methods with relevant software.

It is the objective of the study that determination of methods used to decide alternative forms to avoid excessive heat gains during the summer season while providing maximum benefit from the sun's rays during the winter season. Therefore, samples that can generate input are selected.

1.4. Method

Written sources such as thesis, articles, analyses and photographs which are shown in references will serve as the basis for the study. Graphs, charts and samples will be used to provide details. Performance-based design and digital design will be detailed; methods will be compared to one another; and the effects on building envelope will be presented. When the samples which the configuration depending on the angle of the sunlight for building envelopes for the maximum efficiency in energy save or gain are examined. In this context, it is aimed to identify the Strong, Weaknesses, Opportunities and Threats aspects of the current building envelope design methods by SWOT analysis.

2. RELATIONSHIP BETWEEN PERFORMANCE BASED DESIGN AND DIGITAL DESIGN

The terms that are transferred to architecture discipline before are insufficient in explaining the spatial practices, thus caused people to search for new terms [5]. The term that is searched for a long time is found to be performance, which is thought to be the mainstream approach for architecture discipline [6]. The great change that occurred with calculation altered the ways we perceive and represent a place and the spatial images in our minds [7]. The concept of performance suggests that people see the buildings as active agents in their relationships with environment, and buildings can achieve reality only via actions, gestures, performances and performative facts [8].

After performance concept is used in buildings in 70s, the terms performance-based building or performance-based design are used in studies that are conducted to perform and generalize this concept. In fact, the point these terms are referring is identical. The purpose is to design and build high performance buildings [9]. Performance-based design is defined by Oxman (2008) as the synthesis of two features, geometric formation with digital design and simulation-based performance evaluation. Performance is the determinant factor for shape and geometry included in design process [1]. A transition from forming a shape to finding a peace takes place. During that transition, building performance acts as the guiding factor.

Geometric or materialistic features of the model become more certain at the end of the process, and parametric design systems stand at the centre of the main system. Projections regarding the behavior of the system are based not only on the analysis but also on the performance data and interaction with the environment [10]. As seen in Figure 2, Schewede (2006) defines simulation as the bridge between designer and digital presentation [10].
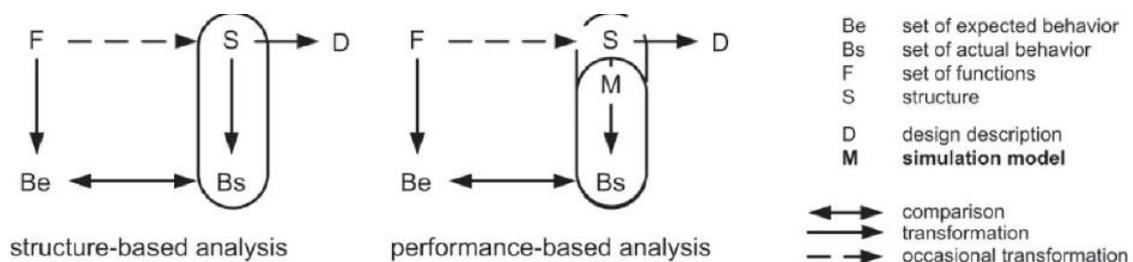

Figure 2. Design processes based on structure and performance [10]

Kolarevic ve Malkavi (2005) mentions about the finite element method which indicates structural energy and fluid analyses that are performed by dividing the geometric model into triangular units for performance analysis on computer [11]. Performance analysis of places with complicated shapes can be performed with such method, and developments in computer graphics facilitate the use of these methods. Performance-based design methods indicate the methods that are created considering the performance analyses of architectural design process. Building performance may be related to technical data such as environmental,

structural and acoustical features or to various features a designer expect from the place. For example, various performance criteria for various factors such as pedestrian-traffic flow, spatial relationships, building program and economic parameters can be determined [12]. Different simulation programs are developed to performed performance analysis on computer. The main purpose is to provide optimum solutions and performance.

Performance-based design is defined as constructing buildings that are user-friendly. These designs provide buildings the ability to move or alter the volume level in the environment with the receivers installed on buildings. Therefore, computer programs that form digital design are used for these solutions. It is possible to create digital design by using different design methods such as Computer Aided Design, parametric design and BIM with using these computer programs.

- **Computer Aided Design:** Most of the drawing and modeling tools that have been used by users for years are Computer Aided Design (CAD) based. These non-parametric programs can only be considered traditional tools as they have the features of 2-D drawing and 3-D visual rendering. The most widely used programs are SketchUp (last Software), AutoCAD (Autodesk), 3D Studio Max (Kinetix), and Maya (Autodesk) tools [13].

These programs come back to us with a number of plug-ins in the process since the day they are set up. For example, since obtaining three-dimensional data at the first time of the programs is not very high quality, the designer can only draw two-dimensional plans, sections, looks and details, whereas nowadays three-dimensional modeling and animations can be made.

Developing the demonstration methods for the designs with presentational purposes is aimed. The way you design the building envelope determines the way you receive a visual presentation (Figure 3), [14].
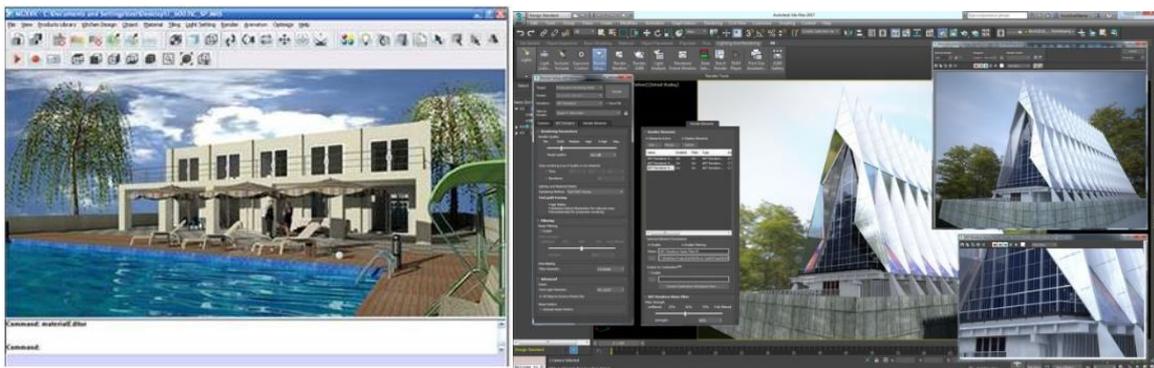

Figure 3. 3D Max and sketch up building modelling examples [14]

- **Parametrik design:** Processes of facilitating the alterations in a parametric system and testing many alternatives by altering parameter values are present. The parameter can be expressed as a case being one or more of a modifiable quantity. With this feature, parametric design differs from traditional design approach and it is also the basis of numerical design.

The design process for parametric modeling consists of many stages such as the formation of the design concept, the shaping of the area in which the design will be made, and the solving of the application details.

In the process of creating a parametric design concept, environmental data or other factors that are decided are interpreted as parameters, thus a design form is created by the effect – response method (Figure 4). Since the design process takes place in a variable system, different alternatives can be easily tried depending on the variables in the design.
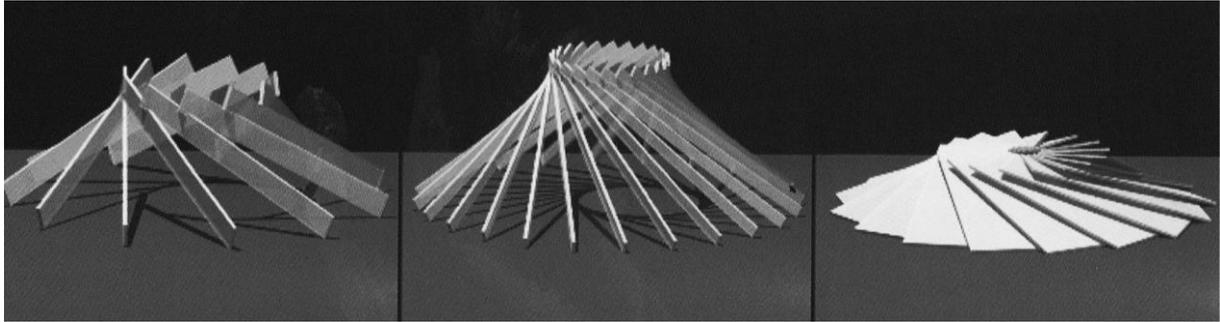
Figure 4. *Parametric modelling examples [14]*

Since parametric design concept will be created through a computer software, the design process has to be highly planned and systematic. The most widely used parametric programs are Autodesk Revit, Rhino-Grasshopper, ParaCloud Modeler, Generative Components and CATIA tools [13].

- **BIM and Its Effects on Building Envelope Configuration:** A three-dimensional model (3D) creates considering all formal graphic data of the design and numerical data such as material, cost, Physical Environmental Control. Building information modeling (BIM) approach that enables joint use of the building through the components involved in the project process throughout its life cycle [15].

BIM process consists of 5 stages:
- 3D modeling and visual design
- Analysis process-simulation and design relationship
- Project and partnership of the resulting product
- Application management
- Building Life Cycle Support [15].

The most widely used parametric programs are Autodesk Revit, Rhino-Grasshopper, ParaCloud Modeler, Generative Components and CATIA tools [13].

The final product of the design is associated with the architectural elements and transformed into the BIM model. The design is developed with three methods:

➤ Use of geometric mass creation commands in shaping the model (Figure 5).
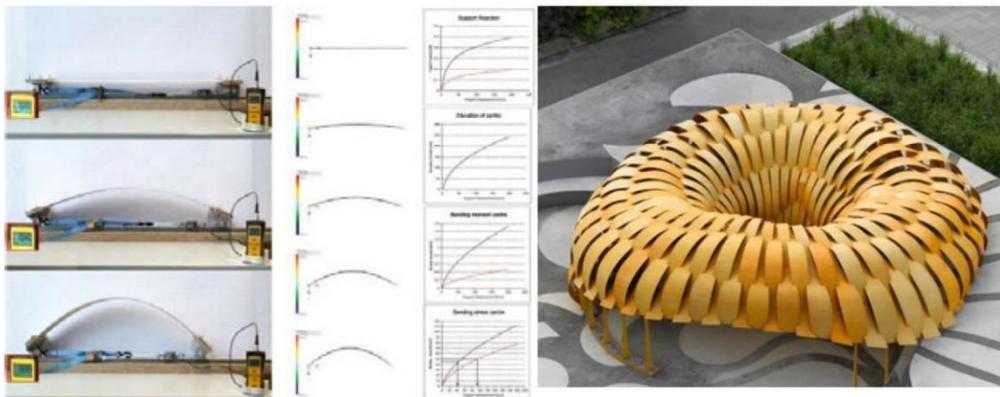

Figure 5. *Geometric mass formation [16]*

➤ Use of script language and parametric design principles in shaping the model (Figure 6).
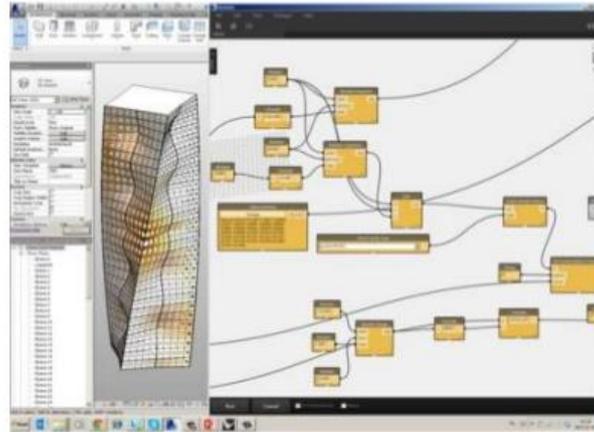
Figure 6. Script language in structure shell design *[15]*

➢ Performance analysis of the model for shaping the model (Figure 7).
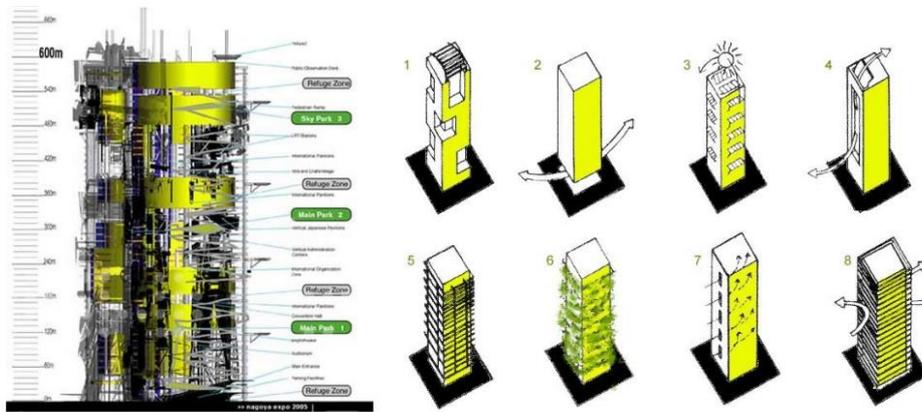
Figure 7. Development of design with performance analysis *[16]*

3. OPTIMUM BUILDING ENVELOPE DESIGN METHODS BASED ON SOLAR PERFORMANCE

3.1. Ideal Design Process and Design Methods

Ideal design process is cyclical. The design can be revised at any stage of the project (Figure 8), [17].
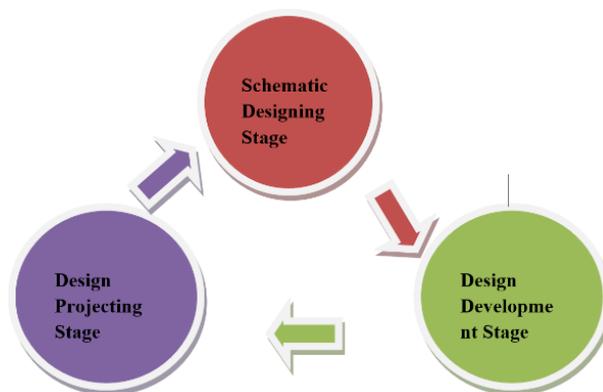

Figure 8. Cyclical design process [17]

Any change that will be made on the parameters will be reflected on the model, thus ensuring automatic update for the data as solar building envelope optimization is a parametric method. In addition, instant calculation and real-time design test features will be available. Therefore, the methods that will be considered as reference can be integrated to the design process in the first or last stage.

The methods that are used in the cyclical design process are as follows:

- Algorithm: Algorithm is defined as the set of steps necessary for solving a problem. In cases where more than one solution is present, the option that fits the operation system and conditions is selected. This algorithmic solution can be transferred to computer via certain sets of rules. These sets are programming languages [18], (Figure 9).

Design process and visibility is facilitated as designers approach towards the design problem with algorithmic point of view.
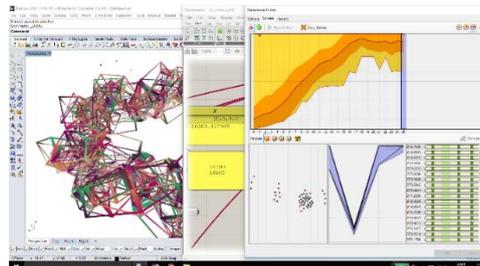

Figure 9. Use of algorithm in design [19]

- **Origami:** Origami, known as Japanese folding art, is based on geometry, consistency and order. In addition, the shape, three-dimensional form and structure are important, too. Modular structures are joined by interlocking [20], (Figure 10).

Figure 10. Design concept of Al Bahr Towers, details of foldable shading element [20]

- **Biomimetic Method:** Natural designs are perfect in every aspect. All features such as aesthetics, flawless functionality and durableness, which an architectural design should have, can be found in these designs [21], (Figure 11).

Figure 11. Flying bird-Milwaukee Art Museum and Aldar Headquarters-sea shell [22]

- **Folding Method (Louvered Grid Shell):** Folding method reduces the negative effects on buildings caused by passive UV radiation. This method provides maximum benefit from the sun as it enables opening or closing according to solar data such as solar angle and distance to the sun [23]. Figure 12 presents an example of shading analysis. UV index is 2.5 or higher in this example. Figure 12a shows certain vectors from the critical solar position to the point cloud area. The points that stay on these vectors and cross the specified space plane are positioned parallel to the plane indicated by the target-shade area, and they formed a point cloud. This point cloud and space plane is presented in Figure 12b. This point cloud lies between the critical solar vectors and the plane in a position parallel to ground level [23].
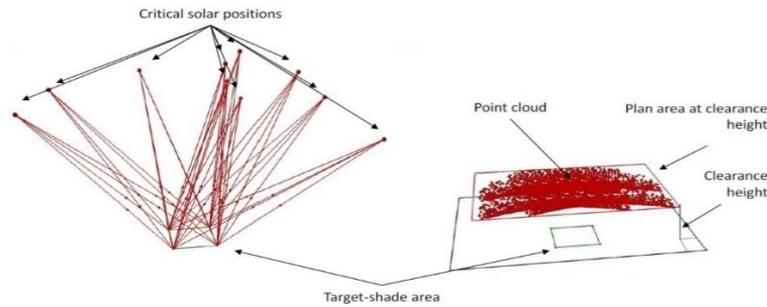
Figure 12.a.*Certain vectors [23]*   **Figure 12.b.***Point cloud and space plane [23]*

The method for taking a form is displayed in Figure 13a which has spring geometry that is supported from four corners on grid web junction. Figure 13b indicates an uncomplicated web junction positioned in a curvilinear area for creating a plane that is in connection with the spring. As displayed in Figure 13c in a reverse position, the web is stiffened and an efficient form is created [23].
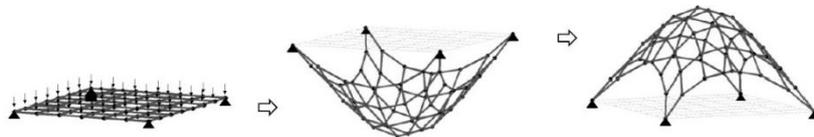
Figure 13.a. Supported grid   **Figure 13.b.** *A web junction*   **Figure 13.c.** *Final form, the process of taking a form [23]*

Figure14 presents the practice of using folding method. A rectangular geometry is selected first, and a web spring supported on four corners is simulated. The practice of taking a form is focused on ensuring that this web is facilitated under gravity loads. Spring junctions can be seen in Figure 14a Figure 14b displays a hanger form containing a mesh. Compressed mesh geometry is achieved reversing this form. The inner view of the prototype is displayed in Figure 14c [23].

Figure 14.a. *Southwest*   **Figure 14.b.** *Northwest*   **Figure 14.c.** *Inner view of prototype   structure, louvered grid Shell prototype [23]*

Practicability of four methods varies by the design. Algorithm, origami and biomimetic methods are the starting points that direct the design. Regarding the folding method (Louvered Grid Shell), no data is present before the design process. The method is used in design, and it shapes the design.

3.2. Optimization of Design and Usage Methods

The main purpose is to find the optimum solution by testing many alternative scenarios for optimizing the designs for energy efficiency. While seeking the optimum solution, building façade becomes one of the most significant points for energy efficiency. Any change that will be made on one of the parameters for energy efficiency will change the energy demand of buildings and affect different systems such as heating, cooling, ventilation and illumination. Therefore, capacity and control methods of each system have to be revised. Any change may act like domino causing all tiles (main systems of a building) to fall [24].

Firstly, building models are modelled according to the desired location and direction information in the building energy modelling program as three dimension (3D) masses in accordance with the architectural

project. Energy efficiency values of building as heating-cooling and mechanical ventilation systems (such as COP) and types (such as fan-coil, heat pump, VRF, roof-top) are entered into the Building Energy Program.

In the light of all this information, the building energy modeling program lists the energy consumption values of the building on an hourly, daily and monthly basis. It also reports the heating and cooling loads per square meter as kWh hour. In this way, the knowledge of how much energy the building will consume during the design phase is reached and can be drawn road map about which model to choose to increase the building's energy efficiency [25].

Algorithms can transfer the term of natural development to computers and almost simulate natural development for finding the most convenient solutions for a certain group. In complicated cases where traditional methods may fail, estimated optimization methods which include genetic algorithms can provide solutions in a reasonable time (Figure 15), [26].
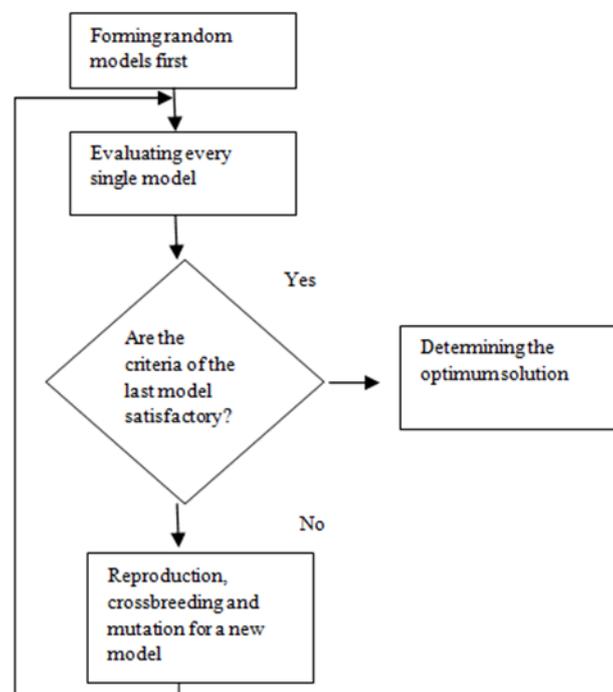

Figure 15. Algorithm flow chart [26]

3.3. Methods of Design Solar-Based Building Envelope

Solar energy has the most effective role in achieving energy targets as it is easier to apply to buildings and solar technology is developing and spreading fast. Thus, the most common methods are design methods that are formed using regular and irregular modular forms. In addition to these methods, solar rays method formed by using direct solar rays is used, too.

➢ **Design Method 1 – Regular Modular Form**

This form indicates the formation of building envelope surfaces by rotating the modular masses in regular forms to expand or conserve the areas where solar rays are collected. In order to provide optimum heat gain and heat save, according to the season, the sun's rays coming to the mass within a certain time period for every season are detected and the most appropriate angles are determined by simultaneous analysis in computer program and the masses are rotated according to these angles. The mass is not movable and the angles of the masses do not change seasonally according to the demand for the sun's rays. This design method may be created by using algorithm, origami and biomimetic design methods together.

As an example, building envelope of Building Os-University housing building is the most basic model of "the design method with regular modular form." Building Os – University Housing design is created by Institute for Advanced Architecture of Catalonia (IAAC) using this method (Figure 16), [27].

Figure 16. BuildingOs – University Housing Building [27]

The building is in Barcelona in Spain and it is located at 41° 23 'North latitudes and 2° 10' east longitudes. The city has a mild climate and temperature about 8-15 degrees in winters and rising up to 30 degrees in summers (Figure 17), [27].
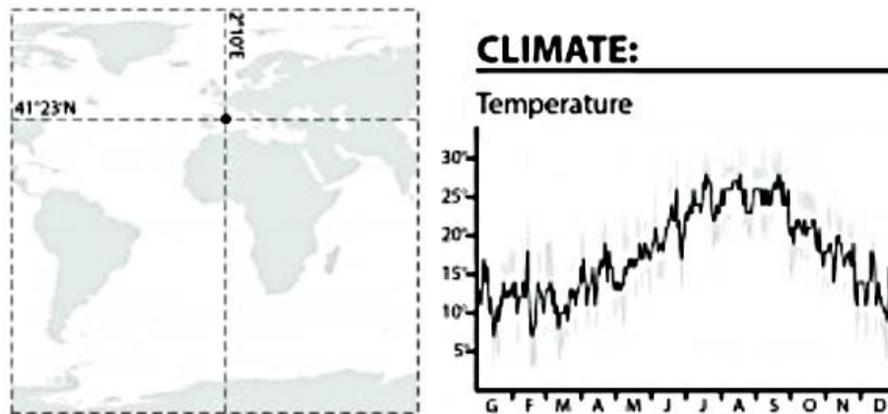
Figure 17. Geographical location and climatic conditions of the building [27]

According to the Barcelona climate, it is aimed for the building at preventing excessive heat gains during the summer season, as opposed to benefiting from the sun's rays. The sun's rays that coming to the building at specific time period are detected and the most appropriate angles are determined by simultaneous analysis in the computer program and the forms are rotated according to these angles. As a form, rectangular is chosen as a regular modular form during the design process. Alternative locations are created by rotating this form in different variations and angles depend on the sun rays (Figure 18).
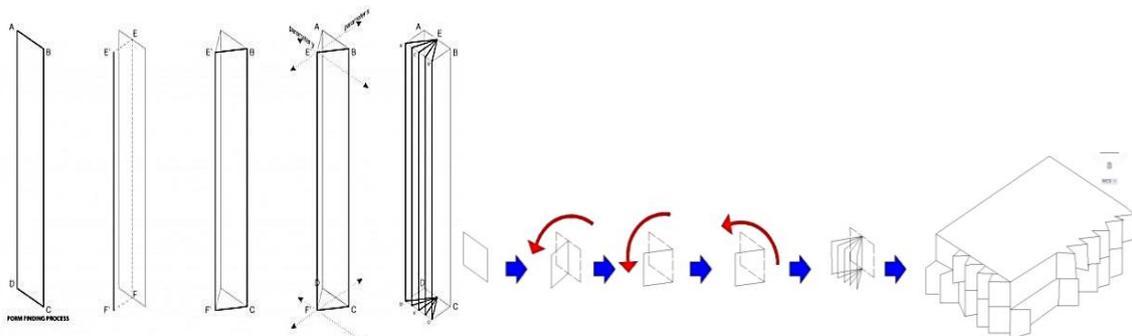

Figure 18. Modular form formation alternatives [27]

Decisions regarding the building envelope designs are made and solar climate analyses are performed in Rhino-Grasshopper program. Different combination sets are considered for selecting the optimum model (Figures 19 and 20).
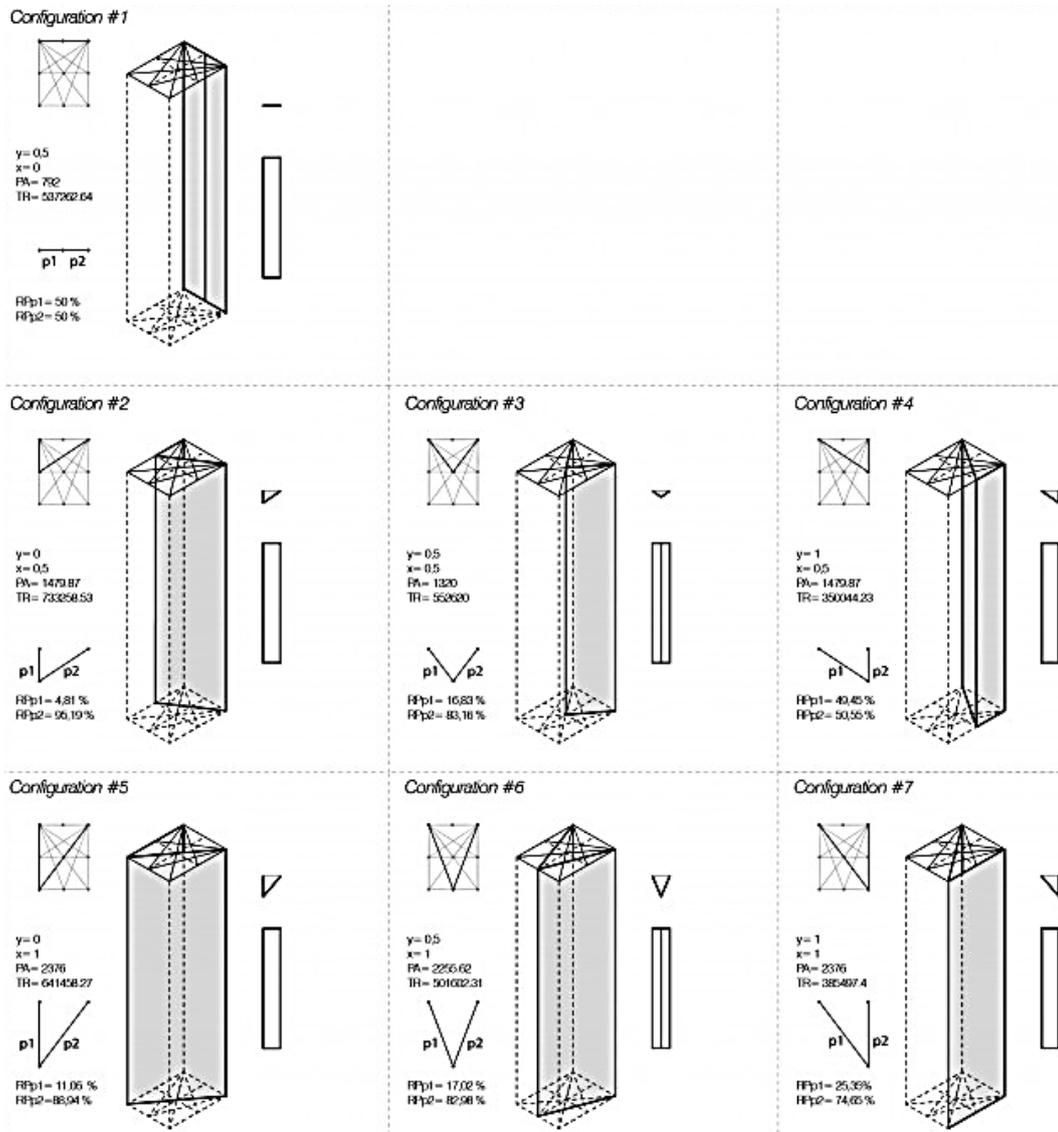

**Figure 19.** *South facade consisting of 33 modules (0.75 m x 3.2m) [27]*
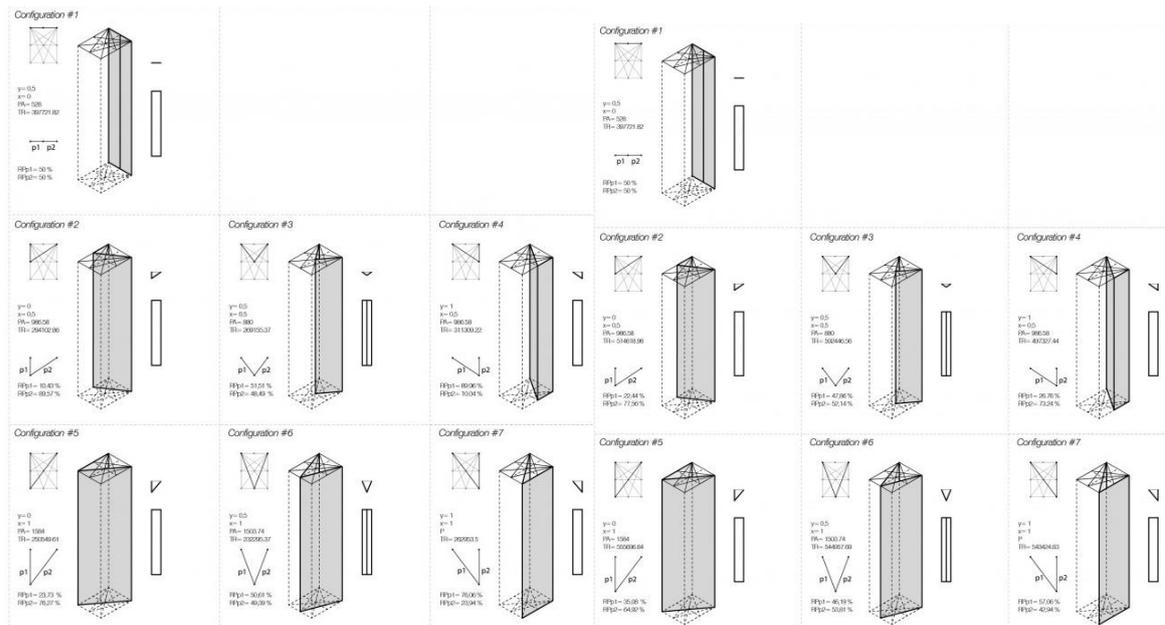
Figure 20. *East and west facade consisting of 22 modules (0.75 m x 3.2m)* [27]

Optimum solution models are specified for making evaluations for each front and the latest model is achieved (Figure 21).
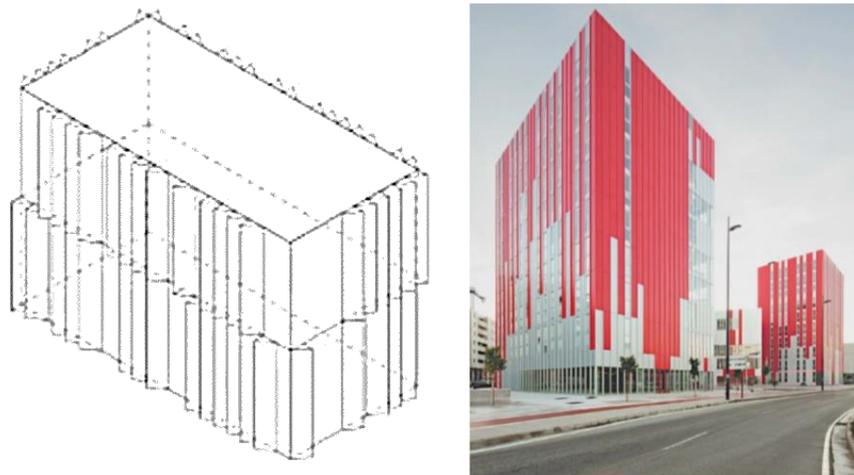

Figure 21. *Optimum shape achieved at the end of analyses* [27]

Design Method 1 – The design started with Regular Modular Form and optimum result is achieved with the analyses performed on Rhino-Grasshopper. A ten-storey 408,375m² building with optimum building envelope has 21,3% energy efficiency and 1576858.16 kWh radiation [27].

> **Design Method 2 – Irregular Modular Form**

Irregular Modular Form method indicates the free usage of parametric model to define a set of design criteria with qualitative and geometric concept. As with the regular modular form method, the most appropriate angles to the forms are determined in each season and within a certain time period to ensure optimum heat gain and heat save according to the season. And the forms are rotated according to these angles. This design method may be formed using algorithm, origami and biomimetic design methods, as in regular modular form.

As the building envelope of Texas University Thermal Laboratory building is designed by rotating the forms at different dimensions and angles according to the solar rays, it is the most basic model of "the

design method with irregular modular form". Beaman and Bader completed the building of the Thermal Laboratory in 2010 in Austin, Texas, United States, which has a mild temperate climate. As seen in Figure 22, monthly solar radiation amounts are reached on each facade of the building. Accordingly, the building requires a high degree of isolation from solar radiation. Since the maximum amount of radiation is on the south facade of the building, a design aimed at day-long shading has been developed on the south facade. This study aims to form day-long shading that is effective in seasons with high thermal gain. (Figure 22), [28].
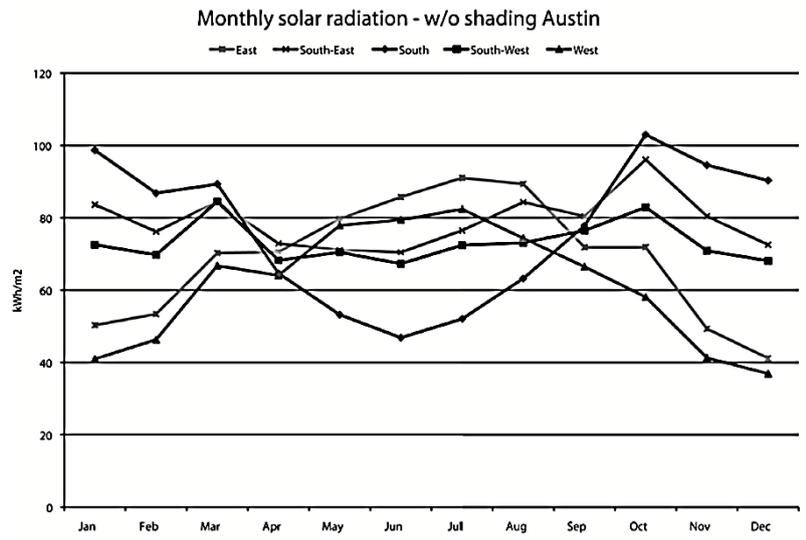

Figure 22. *Monthly solar radiation amounts for thermal laboratory facades [28]*

As you can see Figure 23, irregular modular forms are used in design process. Although there are similar components between these forms, they are angularly and dimensionally different [28].

Figure 23. *Details of shading structure in thermal laboratory [28]*

Angular formation is specified by the specific solar data. Component dimensions are specified by phenomenological conditions. This condition is based on the concept that every person perceives the world personally. People perceive the image created by the outer world. Accordingly, dimensions of components are shaped by designers' perception. These combinations are formed with data-based parametric models on Rhino-Grasshopper which is tested for shape and performance.

These shapes forming the building envelope are designed in two steps:

Step 1; Data of regular modular form are used for traditional shading tools (horizontal and vertical systems) (Figure 24), [28].
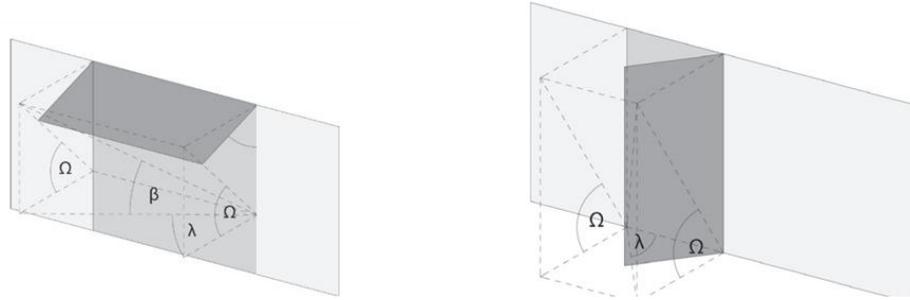
Figure 24. *Horizontal shading tool and vertical shading tool [28]*

The sun's rays are determined in a desired time period and the most appropriate angles are determined by simultaneous analysis in the Grasshopper program, and the forms are rotated depend on these angles. The analysis of horizontal and vertical shading elements that are formed by rotating the regular modular forms at certain angles is displayed in Figure 25.
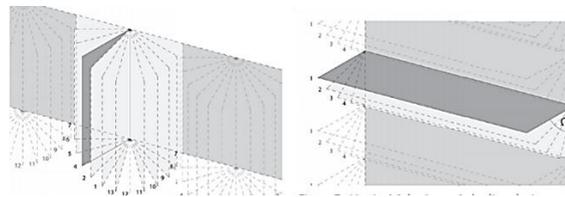

Figure 25. *Juncture rotation tests of horizontal and vertical shading elements [28]*

Step 2; finally, analyses are performed with vertical and horizontal alternative sets for choosing the optimum on building façade (Figure 26).
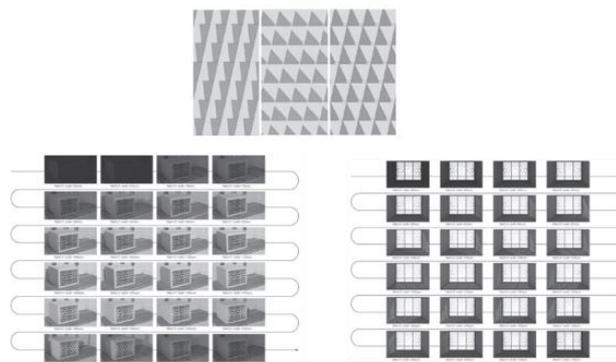

Figure 26. *Shading analyses [28]*

Prototype shading elements are produced at different sizes considering the solar data (Figure 27).

Figure 27. *Shading elements with built-in hanger system [28]*

Performances are compared at the end of analyses and an optimum solution providing shading at 95-100% is found. In addition, energy efficiency increased largely during solar positions [28].

➢ **Design Method 3 - Solar Rays Method**

A roughly solid form of the area is created in square meter and height before initiating the design in Solar Rays Method. The purpose here is to create a design form using the solar rays without preparing a modular shape. This design method can be created using Louvered Grid Shell method.

As an example for this design method, Chromatic Responsive Skins (2013-2014) building envelope is created to be in a cover form, and this envelope received solar rays at certain times. Solar rays are used as design method and all phases of the method are clearly defined. This work is a research project created to present architectural practices that are sensitive to solar rays. It consists of the system called "Photochromic Powders", the material with changing colours, and created in IAAC [29].

The location of the building is located in Sydney/Australia at latitudes 151.215875 and coordinates - 33.859894 (Figure 28) The climate of Sydney is humid subtropical, shifting from mild and cool in winter to warm and hot in the summer [29].
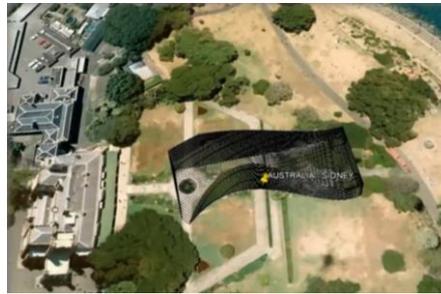

Figure 28. *The location of the design* [29]

Due to the climate conditions of the building, it is decided that the design should focus on both heat recovery and heat conservation, which can respond to changing climatic conditions (Figure 29).

Figure 29. *Passive shading (Passive Shading Skin, Photochromic System)* [29]

With high quality smart material used in design, the building reacts to the changing environmental conditions. In other words, building facades are dynamic. The building turns into green when it is raining and into pink when the weather is sunny. The fronts simultaneously react to changing conditions (Figure 30), [29].
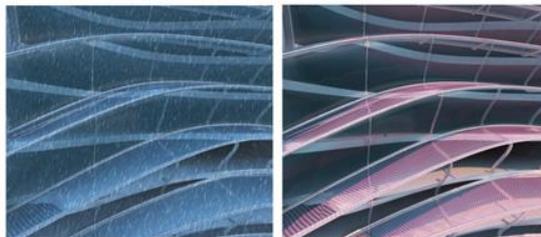

Figure 30. *The colour scale changing when the system is active and inactive [29]*

Before starting the design process, a roughly solid form of the area is created in square meter and height before initiating the design. Afterwards, minimum and maximum angles of solar rays are specified on the building envelope in winter, summer and spring (Figure 31). [29].
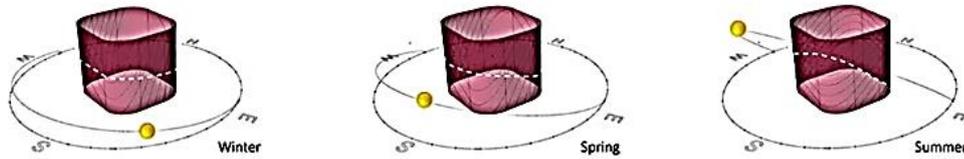

***Figure 31.** Solar rays on the building [29]*

After detecting the average solar ray lines, louver shell system that is perpendicular to the Sun is created (Figure 32).
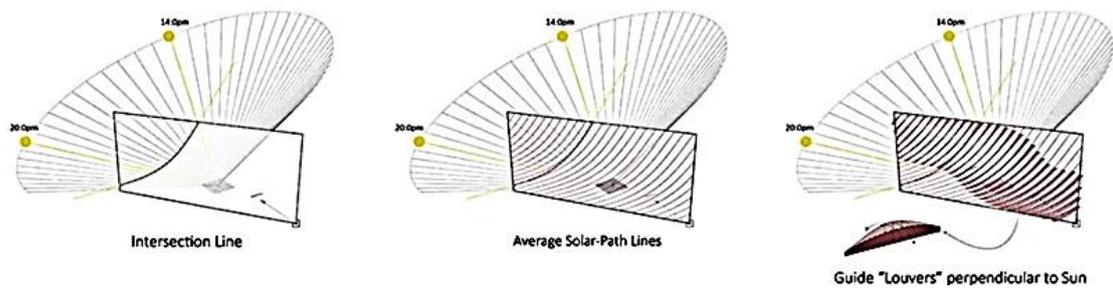

***Figure 32.** Solar rays on the building [29]*

Solar analyses are performed on the louver system, and material is located on the area that is heated the most (where solar rays come in a perpendicular angle). Thus, pigments on the sun could be activated (Figure 33).

***Figure 33.** System with point pattern and material location [29]*

Passive shading system will actively ensure the comfortable conditions indoors (Figure 34).
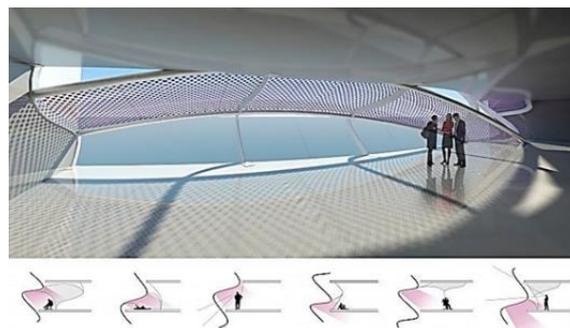

***Figure 34.** System with point pattern and material location [29]*

With the material test, photo chromic practices are found to be the most suitable practices for passive shading and optimum light and heat for architecture.

4. FINDINGS AND EVALUATION

Building envelope design methods are classified as regular modular form, irregular modular form and design methods formed with solar rays. Each method has its pros and cons. These methods are chosen considering the design. Table 1 present a comparison between these methods:

Table 1. *Evaluation of Design Methods*

METHODS OF OPTIMUM BUILDING ENVELOPE DESIGNS BASED ON SOLAR DATA		
DESIGN METHOD – 1	**DESIGN METHOD – 2**	**DESIGN METHOD – 3**
It indicates the forming of building envelope surfaces by rotating regular modular masses at certain angles.	It indicates the free use of parametric model to define the design criteria with quantitative and geometric concept.	It indicates the purpose of creating a design form using the solar rays without preparing a modular shape.
Building Os – University Housing	Austin Thermal Laboratory	Chromatic Responsive Skins
Patras Buildings, Greece	World Fab Condenser	Solaris Tower
Growing Tensegrity	Solar Decathlon	Endesa Pavilion
Tensegrity	Develop Material System	A New Structure Design, Amsterdam
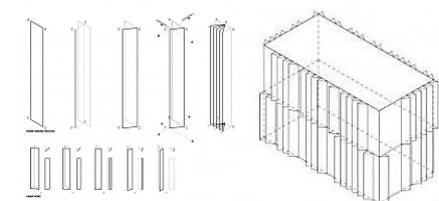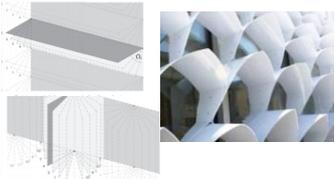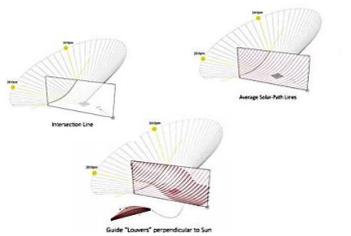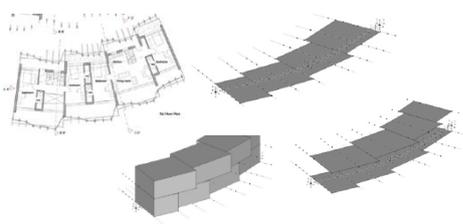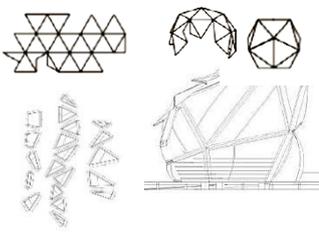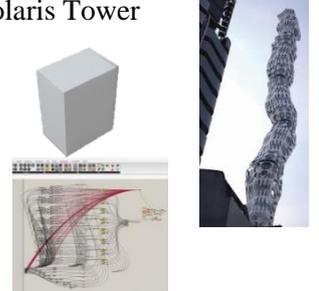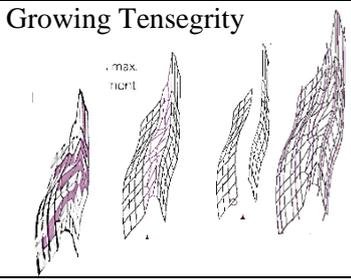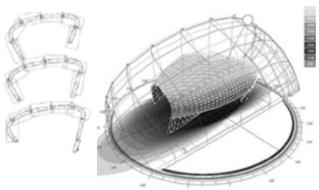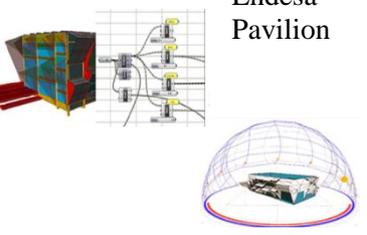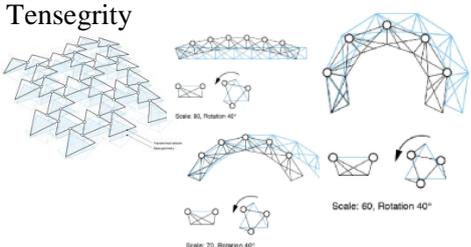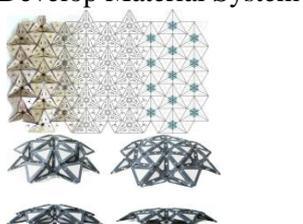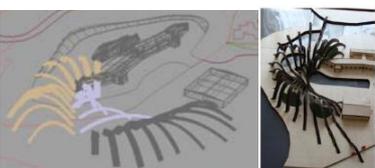
By SWOT analysis of these building envelope design methods, it is determined that these design methods are insufficient in the design process. Thus, the adequacy of design methods connected to solar data are questioned in every context and the situations where it is insufficient are determined. SWOT analysis for the methods is indicated in Table 2. According to this table, the most ideal method ise determined by identifying the strengths and weaknesses,

Table 2. *SWOT analysis for design methods*

	METHOD 1	METHOD 2	METHOD 3
STRENGTHS (+)	Regular variations	Filexible solutions	Without looking for any form direct formatting
WEAKNESSES(−)	Reaching the optimum solution takes long time because of the certain patterns	Waste of time in the design process as regular form is used in the first place	Problems can be encounterd in application phase since alternative shapes consist of non-moduler different angles and forms
OPPORTUNITIES (+)	Creating systematic solution process	Reaching the optimum solution faster than Method 1	Reaching the optimum solution fastest than the othes
THREATS (−)	Unavailability of built environment	Unavailability of built environment	Unavailability of built environment

The strengths of the methods are that while creating regular and flexible solutions for designs using a exact form in the first step, in Method 3 beginning design without the need to find any form.

The opportunity is that creating a systematic design process for designs based on a form, whereas for Method 3, a faster accessing to the optimum result than other methods.

The weaknesses of Method 1 and Method 2 are the design processes take longer time as the number of stages in design period. In Method 3, building applications are more difficult than other methods because of the irregular or amorphous forms that are not fixed angles.

The threats are that all three design methods can not be used in the built environment.

Each of the design methods has its own strengths, weaknesses and opportunities. The designer is free to choose the method he/she wants in accordance with the model. Method 1 and Method 2 are the most time consuming methods. In any case, the third method can be considered the ideal option (Table 3).

Table 3. *SWOT Analysis Evaluation Table*

METHODS / ANALYSES	POTENTIALS				ISSUES			
	Regular variations	Reaching optimum solution fastest	Systematic and regular design process	Flexible Solutions	Searching for initial regular/irregular form	Loss of time during design process	Ability to design monotonous buildings	Inability to be used within built environments
1 Design Method 1 Regular Modular Form	●		●		●	●	●	●
2 Design Method 2 Irregular Modular Form				●		●		●
3 Designe Method 3 Solar Rays		●	●	●				●
CONCLUSION — Design Method 1 Regular Modular Form	● ●				● ● ● ●			
CONCLUSION — Design Method 2 Irregular Modular Form	●				● ●			
CONCLUSION — Designe Method 3 Solar Rays	● ● ●				●			

Evaluations indicate that regular modular form method enables researchers to prepare new regular form variations. Therefore, the most significant advantage of this method is that it provides a solution process that is more systematic than other methods. However, it should be noted that it will be harder to achieve optimum solution as regular modular forms consist of components that are similar.

The advantage of irregular modular form method is that it can prepare variations that are different by angles and dimensions, therefore enabling faster achievement of optimum solution. However, the design process consists of two stages in this method as irregular forms are created using parametric data. Thus, the time to achieve the optimum form increases.

Optimum solutions can be achieved in a shorter time with solar rays method as regular or irregular forms are directly formed on Rhino-Grasshopper.

5. CONCLUSION AND RECOMMENDATIONS

Performance evaluation is performed since the beginning of the design process to ensure a sustainable design in energy-efficiency context. It is critical to measure whether or not the buildings with high performance fulfill targeted performance criteria. These targets may be evaluated with certain analyses. With the calculating and parametric tools of numerical design and simulation software made it possible to complete the process effectively and correctly. With the designs, it is mainly possible to analyze the energy consumption, day light intake, relationship between the solar activities and shade, radiation gain, wind usage and natural ventilation [30]. The design concept called Design Based on Building Performance includes architectural sustainability principles and physical environmental conditions in design process as digital and measurable factors. This concept is a spiral design approach that performs real-time measurement on building performance and creates solutions [31]. If designers wish to test design options for choosing the best, they have to simulate every option separately and compare the results. The purpose here is to choose a design option and thus achieve the best solution by reducing or increasing the parameter values and comparing the results.

The aimed performance criterion of this study is "solar preservation/gain". Three methods are used to achieve the optimum solution. There are differences in applications of Methods 1 and 2. It is possible to achieve the irregular form (Method 2) by rotating the regular form (Method 1) a couple of times. Method 1 is used as the first step in Method 2. In both methods, analyses of Grasshopper alternatives are performed to achieve the final form.

In Method 3, a roughly solid form of the area is created in square meter and height before initiating the design, which is different than other two methods. Other design processes are formed by the solar rays on Rhino-Grasshopper program, and analysis is performed. Thus, Method 3 provides a faster and easier design process than other methods and with SWOT analysis, it is determined that it was the most appropriate method that could easily reach the optimum solution among other methods. On the other hand, in all of the existing methods, the structures/buildings in the close area of the design and that would cast a shade on the design are not taken into consideration. So, it is thought that this problem can be solved by using the methods together with the "Solar envelope" method.

The solar envelope method is a theoretical method used to provide sunbathing in buildings and in the built environment [32]. According to Hopuer (2003) [33], the solar envelope is the maximum potential volume within the built environment that does not cast a shadow on the buildings in a certain period of time [34].

This method can be use with manual calculation and can also be applied by using today's technologies. Some of the computer programs have the solar envelope component as a parametric script tool. The time period is determined to calculate the arrival angles of the sun's rays. When applying the solar envelope method with this component, the built environment at a fixed location is defined and with the direction of the design area is also taken into account.

Figure 35 shows an example of the solar envelope method. The solar envelope component is applied to the design area at 38 degrees latitude in the 10:00-14:00 hours range in 21th June and 21th December which are solstice days. The sun rays, which came to four different masses in this hour range, formed an envelope of different vertical heights in triangular shape according to daily and seasonal limitations. The maximum mass that does not shadow each other is revealed via the intersection between December and June solar Shell [35].
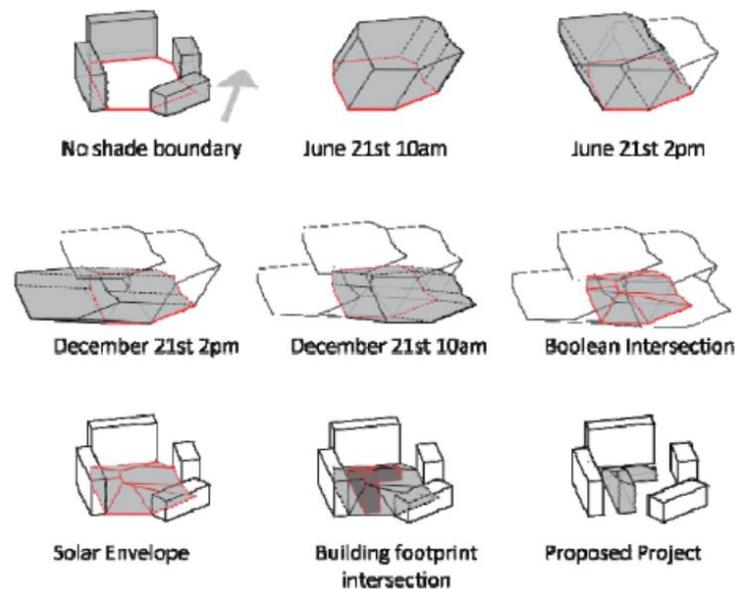

Figure 35. Example of use of solar envelope method [35]

Although using various energy calculation programs may seem to be a solution, these programs with genetic algorithms to achieve stereotypical results. However, the design must be under the control of the architects. Architecture can not be considered different from art and as a designer, the architect should be able to design the most appropriate one in terms of energy consumption and environmental impacts. For this purpose, "Solar Envelope" and "Solar Rays" methods can be used together to make designs that take into account the potential of the shadow and gain or save solar energy.

The artistic aspect of architecture should not be disregarded considering the potential of performing designs sensitive to environmental formation, achieving passive solar energy, and ensuring natural illumination. The architect has to develop the design by making a separate effort in the limited volume, which is in

accordance with the methodological characteristics. Therefore, it is a must to follow the rhythmic movements of sun that vary by place and time. This new method is "the synthesis of time and place".

This method will guide the new methods in new practices. Thus, it is thought to serve as a significant approach in ensuring optimum energy gain while minimizing the energy loss. In addition to providing energy gain in construction sector, this method will also contribute to the domestic economy.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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