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Early-Stage Design Optimization of Primary School Building's Geometry with Reference to Energy Performance

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Abstract Since the early stages of design have the most important impact on building performance and general decisions regarding the geometry of the building are made at this stage, this article deals with energy optimization in the initial stages of design. This research aims to provide a method to help architects find the proper geometry of the building to reduce energy consumption in the initial design steps. In this article, a parametric generative model, which was created in the Grasshopper plugin environment in Rhino, is used. Here, the determining variables of the building geometry include the orientation, WWR, and the shape composition of the building form, then the Honeybee plugin is used to calculate the Energy Use Intensity (EUI) and find the optimal geometry. In general, in this research, the optimal form of the building mainly has a rectangular or square plan, and the forms with a large contact surface with the surrounding environment have been recognized as inappropriate, in addition to that, the optimal orientation is variable based on two other parameters and is mostly 0 or 15. The WWR for the top models was mostly 20 and in sometimes 30. Generally, in this research, the lowest EUI of 93.18 kWh/m2 and the highest EUI of 125.93 kWh/m2 were reported, which indicates a difference of about 32% in the amount of energy consumption of different geometries for an educational building in this context. The results show that architects can use the method adopted in this article as an effective method to reduce building energy consumption in the early stages of design.

Keywords: *optimization, form finding, energy consumption, early-stage design*

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1. Introduction

Building energy efficiency is mainly determined at the design stage, which is considered as the best opportunity to improve the energy performance of buildings [1]. Since the early stages of design have the most important impact on the comfort of users and the performance of the building [2], this article deals with optimization in the initial stages of design. According to a survey of researchers and designers, in most cases, an energy model is created for consideration in the early stages of design or design concept between different design stages. In the early stages of design, where the general shape and geometry of the building are chosen, there is no need for a complex and advanced model, and only a simple model can achieve its goal [3].

This article aims to present a method for designing the general geometry of preschool buildings to reduce annual energy consumption. considering the most important decisions taken in the early stages of design and also paying attention to the importance of speed, variables such as building form, orientation, and window-to-wall ratio (WWR) as the most important factors shaping the geometry of the building for optimization with the aim of Energy Use Intensity (EUI) is considered. Some related studies work on geometry optimization with different objectives and parameters. Still, these studies mostly focus on a few forms, but this article seeks to create a parametric generative model to investigate different possible form compositions and optimize building geometry. In this regard, a parametric model with square modules has been considered in the Grasshopper environment in Rhinoceros, which is capable of creating different forms for the intended two-story preschool school. The form variable, along with the orientation and the amount of WWR, will ultimately determine the geometry of the building. Finally, the Honeybee plugin is used to calculate the annual Energy Use Intensity (EUI) and the genetic algorithm to find the optimal geometry. Architects and designers can use this method for different climates and to achieve optimal geometry. In general, the questions that this research seeks to answer are as follows:

- How can we consider a method for optimization in the early stages of design that can be implemented in similar cases?
- How much energy consumption intensity can be reduced through geometric optimization?
- What are the features of the optimal geometric pattern in the design context?

2. Literature Review and Background

Optimization is a process and a scientific method for design and decision-making that allows exploring a large number of design options optimally and should be as functional and effective as possible [4]. Optimizing building energy design plays an important role in promoting sustainability and confronting some of the critical issues of our generation, such as energy poverty, economic crisis, and climate change. Therefore, scientific research in this field is necessary [5]. Optimization studies are often performed in the early design phase, where most design decisions have not yet been made [6], but mostly, at this stage, the various design options and their effect on the performance of the building are not fully investigated [7]. Architects can use several types of techniques to discover an "optimal" solution, including parametric analysis, genetic algorithms, multi-objective optimization, and even "passive" optimization [8]. Surveys indicate an increase in studies in the field of building energy optimization in recent years. The reasons for this include the higher demand for energy efficiency in building design, which is either required by standards or policies related to energy efficiency, or the development of efficient optimization tools that can easily simulate building energy [5]. Designing an energy-efficient building in the early stages requires fast simulation results of possible building performance [9]. Different design options in the early design stages have a major impact on the building's final energy performance and costs. Therefore, at the beginning of the project, we have more opportunities to improve the final performance of the building [10]. Therefore, paying attention to building energy optimization in the early stages of design can lead to the improvement of building energy performance.

Common design variables considered in optimization studies include building orientation, building shape, building dimensions, building materials, window-to-wall ratio, lighting equipment, and HVAC system sizes. Optimization methods are used for various building design problems such as energy, cost, orientation, facade design, thermal comfort, daylighting, volumetric mass, structure, and life cycle assessment [11]. Building shape and orientation, along with the overall design of the envelope, are the main areas of focus for energy modeling in the early design phase [12]. Therefore, considering that the purpose of this study is to investigate the overall geometry of the building in the early stages of design, as well as paying attention to the speed factor, three basic variables have been considered to introduce the overall geometry of the building, including orientation, form and the WWR.

Many studies have been conducted in the field of building energy consumption optimization, some of which have investigated the effect of orientation on the amount of energy consumption. [4] optimized the performance of daylight, thermal comfort, and energy consumption of a school in the cold climate of China by considering variables such as the orientation of spaces, geometric configuration, WWR, type of canopy, and transparent materials. [12] studied the effect of basic geometric factors on the energy efficiency of tall buildings in several different climates. In this article, variables such as the shape of the plan, the ratio of the dimensions of the plan, the direction of the building, and the windows were investigated. [6] uses a BIM model to accurately estimate the natural ventilation potential of a high-rise residential building in Hong Kong. One of the variables investigated in this research is orientation. In the research [7], the orientation as a variable to investigate the thermal comfort and electrical energy consumption of a residential building with natural ventilation was investigated. [8] studied the effect of factors such as the size and location of openings, building form, building orientation, site design, topography, and physical characteristics on the ventilation coefficients of 61 classrooms. [13] deals with optimizing a primary school classroom by considering energy, daylight performance, and thermal comfort. The results obtained by this research indicate that in almost all the optimal situations, the orientation is equal to 0, which indicates that in Iran, considering the thermal comfort, daylight, and comfort of the users, the optimal orientation of the building is towards the south. [10] has addressed the optimization of the building envelope to improve the thermal and economic performance of the building in two different climates. This research has investigated variables such as building orientation, materials and thermal mass of external walls, insulation thickness, type of opening, and WWR.

In the simplest view and definition of the windows of the building, it can be said that windows are one of the main parts of the building, which provide the task of providing lighting inside the building during the day, ventilation, and visibility to the outside; However, this definition does not include any engineering perspective, even though the proportions and location of the windows play an important role in the energy efficiency of the building [14]. Among building components, windows are always considered weak points of the building in terms of heat transfer [15]. Reducing energy intake through building envelope elements such as windows is a way to combat increased energy consumption [16]. A window with optimal dimensions is one of the important elements of buildings, which is very effective in saving electrical and thermal energy consumption [15] Therefore, choosing the position and proportions of windows, which determine energy consumption and comfort patterns in buildings, is part of the basic decisions of the design process, which will hardly change later. Therefore, the dimensions of the window must be the result of a careful process that considers several issues simultaneously [17]. Several articles have examined the appropriate percentage of the opening relative to the wall surface in various climates with multiple uses, considering the design context and the target climate of this research, which is the city of Babolsar with a temperate climate, and considering the goal of the research, which is to reduce annual energy consumption, The range of 20-40% can be considered as the optimal opening percentage [12] [17,18,19,20,21].

The building form has always been investigated due to its great influence on performance [22]. [23] intending to reduce the primary energy consumption of the classification of tall residential buildings, optimized the form in the concept stage. [24] By considering three goals including light, visual comfort, and thermal condition, optimized the form of a high-rise residential building. In a part of his studies, Olgi has presented the proportions, orientation, and optimal form of the building in different climates [25]. Okeil has researched the field of achieving optimal building form and efficiency in terms of energy consumption. In this research, he presents his proposed form in the latitude of 48 degrees, emphasizing the differences in the field of appropriate forms for buildings in different geographic latitudes and climates. The main scale in this research is the urban block scale. In general, the main and special emphasis of his research is on the form of the building as one of the effective factors in the amount of energy consumption [26]. In their studies, to reduce energy consumption and improve the daylight performance of a commercial building in the early stages of design, Konis et al presented a method to achieve the optimal geometry of the building. In their studies, they introduced a productive method for generating building geometry in the Grasshopper software platform. In their studies, strategies such as natural ventilation, daylight, and sunlight control have been considered in four different climates. The variables investigated in this research include building form, WWR, and external canopy [27]. In a study conducted to reduce the energy consumption of a high-rise office building in the early stages of design, Babak Raji et al investigated the geometry of the building in three different climates. In these studies, first, some forms were selected and their energy consumption in the three desired climates was evaluated by Design Builder software, then in the next steps, the appropriateness of the plan, orientation, and percentage of the suitable opening of the building was checked [12]. Chen et al. addressed the multi-functional optimization of the building's form and envelope along with considering the cooling load and attention to daylight in the initial design steps. The form production process in their studies is defined as 16 points on the perimeter of a rectangle, with 4 points defined on each side, and the produced form is the result of selecting 4 points from these 16 points, which creates a total of 256 forms. Then the middle yard is created by scaling the form, which has a range of 0.3 to 0.6 [28]. Javanroodi et al present a method called EEF to optimize the reduction of annual energy consumption (cooling and heating) and pay attention to thermal comfort in high-rise office buildings in Tehran. The optimization of his studies is done by the ARCHSIM plugin in the Grasshopper environment that uses the ENERGY PLUS engine. In this method, he uses modular form finding according to the urban context [29]. Haseeb et al investigated the form and optimal orientation of a 10-story building in Kirkuk, Iraq. In this study, first, 6 different forms without orientation (0° direction) were evaluated in terms of energy consumption and cost to identify the model with the lowest energy consumption. In the next step, the models were rotated clockwise by a factor of 15 degrees to determine their energy consumption and cost [30]. As mentioned in the literature review, the optimization of building geometry (including form, orientation, and opening percentage) in the early stages of design can have a great impact on the energy consumption of the building, but studies in this field have mostly investigated a few limited forms or they did not seek to provide a method that can be effective for different uses and climates. Therefore, this research seeks to provide a comprehensive method to help architects and designers make the right decision in the initial steps regarding the form, orientation, and openings, so after selecting the important and primary factors affecting the energy consumption of the building in the initial steps the design is focused on creating parametric modular forms of an elementary school (2 floors) and optimizing them based on annual energy consumption. Since the purpose of this article is to provide a quick and correct method for evaluating building geometry in the early stages of design, strategies such as daylight and natural ventilation, although not as an optimization goal, but as an effective strategy to reduce building energy consumption in evaluating forms are considered.

3. Research Methodology

3.1. Required Software Programs

Parametric design software was introduced for the first time in 2008. Grasshopper is the most popular software that is a graphical algorithm editor and as a parametric 3D software, it is linked to Rhinoceros 3D and helps designers who do not know coding to create their parametric model [13]. In general, automation software helps in analysis by using programming tools. Many studies have spoken about the positive effect of using Grasshopper software to optimize the exterior of the building [22].

In this research, Grasshopper software version 1.0.007 and its plugins Ladybug version 0.0.68 and Honeybee version 0.0.65 are used as energy modeling and simulation programs. It was used for the energy analysis of the selected educational building. Grasshopper is mainly used to create generative algorithms. Ladybug and Honeybee are open-source plugins for Grasshopper to help designers with energy modeling in Grasshopper. The Lady Bug plugin is used to receive reliable weather data approved by Energy Plus, i.e. (EPW) files, check the weather condition, and display the results graphically, and the Honeybee plugin is used to connect to Open Studio for Building energy simulation. In Figure 1, the research process is illustrated.

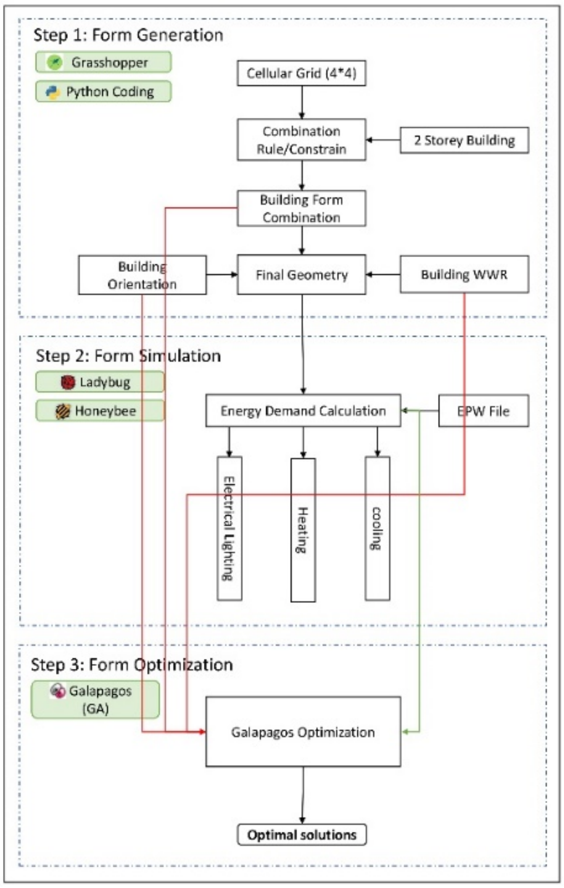

Figure 1. Research methodology

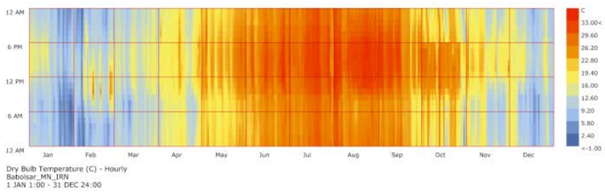

Figure 2. Babolsar Dry Bulb Temperature

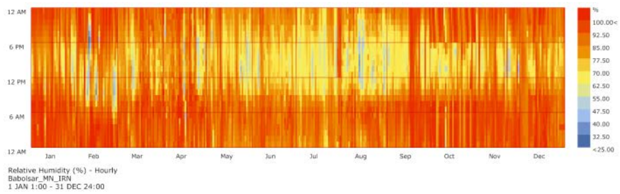

Figure 3. Babolsar Relative Humidity

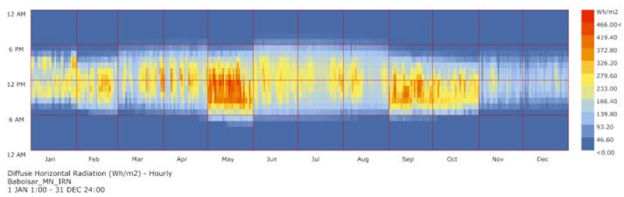

Figure 4. Babolsar Diffuse Horizontal Radiation

3.2. Climate Data

Climate is considered a key driver of energy consumption in buildings as it affects HVAC and DHW energy consumption. In addition, other weather-related conditions, such as daylight, temperature, and humidity, have a large effect on the use of certain equipment (lamps, refrigerators, dryers, etc.) and the number of indoor operating hours [31]. The weather information of Babolsar city in the form of zip file RN_MN_Babolsar.407360 (TMYx) extracted through the Ladybug plugin and from the Ladybug tools website is used as a context weather file. According to weather information, the average annual temperature of Babolsar is 17.3 and the average relative humidity of this city is 80, which is predictable considering that this city is a coastal city.

3.3. Geometry and Design Variables

In these studies, a parametric model has been created in the Grasshopper environment with the help of Python coding. This model was inspired by the EEF model introduced by Javanroudi et al [29], With the difference that the mentioned research used this model to produce the form of a high-rise office building according to the design context, and therefore, the limitations of the form production are different according to the project type that is a high-rise building and the optimization goals. In addition, in the EEF model, the strategy of using natural ventilation and daylight is not considered. Therefore, in this research, the aim is to determine the suitable geometry for a short-story kindergarten in Babolsar city, which has 2 floors, including the ground floor and the first floor. In this study, the process of parametric optimization of building energy to optimize the geometry of the building includes the following steps:

1. Building modeling
2. Energy simulation
3. Optimization

3.3.1. Form Generation

In this research, the goal is to optimize the overall geometry of the building in the early stages of design; Therefore, according to the study of previous research, three variables, including form, orientation, and window-to-wall ratio, have been selected as the most important factors of building geometry, and in a parametric model, the building geometry with the simultaneous effect of these three factors is considered.

Based on the analyses made in the field of accuracy and speed, 4x4 grids were selected for the formation of the form. A 4x4 grid is much faster than a 5x5 or 6x6 grid. In this network, it is possible to create all possible and common building forms (L, T, C, CY, U, ...) and new forms. The constituent modules of this productive model have dimensions of 6.5*6.5 meters and a height of 4. These dimensions were chosen based on the optimal dimensions of the structure and attention to the dimensions and area of the required spaces.

To determine the number of selected modules from these 16 modules for the production of the form, at first, analyses were performed to achieve the optimal proportions of an educational building in this climate, until the number of selected modules has the possibility of creating the optimal proportions required in terms of energy in the design context. Also, taking into account the required area, and the minimum number of modules possible (which creates more diverse forms), 8 modules out of 16 modules were selected to create the form. The selection of 8 modules out of 16 modules has 12,870 different states, which cannot represent an acceptable building form, so restrictions were applied to produce an acceptable form. Based on these restrictions, several unacceptable forms were identified according to Figure 5 and were removed, such as:

1. Forms that have two separate and distant parts
2. Forms whose parts are connected only by corner connection

In this way, finally, 1474 forms were analyzed for simulation and optimization.

In order to evaluate the orientation of the building, since the initial grid has a square shape and any form can occur again with a 90-degree rotation, and also by evaluating the test of an initial model, 0-15-30-45-60-75 angles were selected as orientation variables. Also, the opening percentage compared to the wall surface according to past studies in this climate was determined to be 20-30-40.

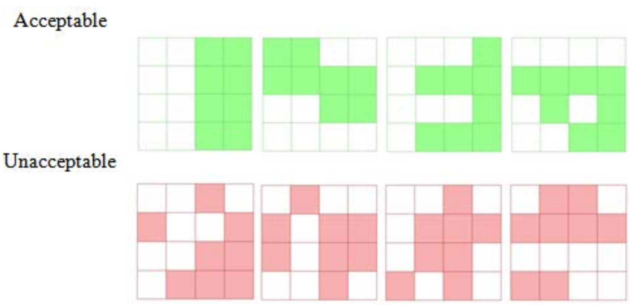

Figure 5. Acceptable and unacceptable forms in simulation

To generate the parametric form, an algorithm was used in the Grasshopper environment, which was created with the help of Python coding. At first, a 4x4 grid with dimensions of 6.5 meters is determined, the desired code created with the help of Python programming takes into account all the selection states of 8 modules out of 16 created modules, and then based on defined limits, some forms are removed and put all forms which are accepted in a category. In the end, the continuation of the algorithm is followed in the Honeybee plugin environment; In this way, each time one of these forms is selected and according to the defined conditions, it examines its annual energy consumption. In Table 1, the investigated variables of the parametric model can be seen.

Table 1. Design Parameters

Variable	Attributes	No. of values
Form	1473-...-2-1-0	1474
Orientation	-60-45-30-15-0 75	6
Window to Wall Ratio (WWR)	40-30-20	3

3.3.2. Form Simulation

In the simulation stage, Rhino software and Grasshopper plugins (Ladybug and Honeybee) have been used. Creating the form in the Grasshopper environment was done in the way mentioned earlier and through a code in the Python environment. Energy simulation is done by the OpenStudio engine through the Honeybee plugin interface. For this purpose, the output of the modeling process in the Grasshopper environment was connected to the Honeybee component. In general, the simulation was carried out to evaluate the Energy Use Intensity (EUI) of the building (kWh/m2) in the form of the sum of the cooling, heating, and lighting energy consumed in the period from 8 am to 8 pm, taking into account the usual activity time of the preschool and dividing it by the total surface area.

For the HVAC system, the ideal loads air system is used in EnergyPlus, which is the most suitable choice for the early-stage design [13]. In the simulation settings, temperatures of 20 and 25 degrees are heating and cooling setpoint, respectively. These numbers have been determined by considering the comfort temperature in Babolsar city, which was obtained by examining the Mahoni table and taking into account the comfort of children. The details of the building program can be seen in Table 2. Among the other settings considered according to Table 3, we can mention the natural ventilation settings taking into account the comfort temperature and the outdoor temperature, as well as the settings related to daylight to provide the minimum required lighting of educational spaces (300 LUX).

Table 2. Building program

Project type	Primary school classroom
Floor area	338m²
Floor	2
Working hours	8 AM- 8PM
Open hours period	5 September- 20 June
Equipment load per area	7.6424 W/m2
Infiltration rate per area	0.0002 m3/s m2
Lighting density per area	11.8404 W/m2
Num. of people per area	0.25 ppl/m2
Ventilation per area	0.0006 m3/s m2
Ventilation per person	0.004719 m3/s

Table 3. Air flow setting

Natural ventilation type	Window natural ventilation
min indoor temperature for natural ventilation	21
Max indoor temperature for natural ventilation	24
min outdoor temperature for natural ventilation	18
Max outdoor temperature for natural ventilation	30
Stack Discharge Coefficient	0.65

The materials considered for the building construction are based on the study of previous research and also considering the ASHRAE standards (ANSI/ASHRAE/IES Standard 90.1-2019) which can be seen in Table 4. Table 5 represents the features of the windows.

Table 4. Construction materials

Construction type	Exterior wall	Floor	Roof
U_Value	0.36	0.55	0.28

Table 5. Window material

U_Value	SHGC	VT
1.960	0.691	0.744

3.3.3. Form Optimization

In general, genetic algorithms are the most popular algorithms for optimizing building performance and have reliable results [32]. Galapagos is a single-purpose optimization tool for Grasshopper, a parametric plugin for Rhino that uses GA or SA to optimize a Grasshopper model or a Rhino model connected to Grasshopper. It can be combined with EnergyPlus for whole building energy simulation and with daylighting analysis tools such as DIVA [5].

In this research, in the last step, optimization of the building geometry based on the Energy Use Intensity (EUI) was investigated. To achieve the optimal geometry, optimization by genetic algorithm, which can be implemented in the Grasshopper environment through the Galapagos operator, has been used. The use of optimization makes it possible to select the best and most optimal value for the intended purpose within the range determined by the designer. As a result, there will be no need for trial-and-error changes by the designer to reach the most optimal state with the set goal, but this operation will be performed by the computer and the genetic algorithm with the highest accuracy and speed.

Galapagos' performance includes two main parts: genome and fitness. In the genome section, the variables of the project, and in the fitness section, the objective function of the project are defined. Galapagos can determine the minimum or maximum value of the objective function as defined in the fitness section. In this project, the genomes, or the variables to be optimized include the form, orientation, and window-to-wall ratio (WWR). The objective function will be the sum of the annual heating, cooling, and electrical energy consumption. This value will be minimized in the optimization process and the geometry of the building will be used in the design in the lowest state of energy intensity.

By executing the Galapagos operator, the genetic algorithm produces different alternatives with the input variables of the genome, and after the completion of the optimization process, the optimized option in terms of energy consumption will be obtained. For this purpose, population 50 and Max.stagnant 20 are considered in this study. Also, the values of initial boost, maintain, and inbreeding were set to 2, 5%, and 75% respectively by default. In Table 6, the optimization settings are specified.

Table 6. Settings of the Galapagos optimization algorithm

Population	Max.Stagnant	Initial Boost	Maintain	Inbreeding
50	20	2	5%	75%

3.3.4. Annual EUI Simulation

Energy intensity is the main indicator of the efficiency of buildings, while this index is only available for the few countries where data on energy consumption and floor area are collected. In developed countries, more efficient buildings and equipment and the multiplicity of energy services have made possible a significant reduction in energy intensity up to roughly 15 koe/m2 [31]. This study aims to reduce the thermal load and lighting energy needs of an educational building. For thermal performance, the heating or cooling load is defined as the amount of thermal load that must be added to or removed from the room air mass to maintain the room air mass temperature at the thermostat setting temperature. In general, for thermal evaluation, the sum of annual hourly heating loads and annual hourly cooling loads is used [13]. The optimization operation with the help of a genetic algorithm is defined as the following relationship:

TEC = ∑Ec + ∑Eh + ∑El

EUI = TEC / S

Ec = Annual energy consumption for cooling (kWh)

Eh = Annual energy consumption for heating (kWh)

El = Annual energy consumption for lighting (kWh)

S = Conditioning floor area (m^2)

TEC (Total Energy Consumption) = Annual thermal and lighting energy (kWh)

EUI (Energy Use Intensity) = Energy use intensity or annual thermal and lighting energy consumption per square meter

4. Findings

In general, according to the defined variables for form, orientation, and WWR, finally, 1474 forms were analyzed for simulation and optimization. Since the research aims to achieve the optimal geometry concerning the lowest amount of annual energy consumption, the forms that have the lowest EUI among the results have been identified in Figure 6. By analyzing the results, it can be concluded that the effect of the form is greater than the orientation, because although the orientation angle of the top models is mostly 0 or 15 degrees, for the more optimal form, this angle is also recorded up to 45 degrees, then the next form is placed in the next rank. By analyzing the optimal forms, it can be seen that in this project elongated rectangular forms and then close to square forms and similar forms have superiority. For the orientation, a specific number cannot be introduced as the best orientation because it has been observed that this number is completely variable based on the form. For one form combination, the best orientation is 0; for another, the best orientation is 15 or so. Still, for the same form combination, 0 or 15 degrees are usually proposed as the optimal orientation which shows the desire to create a form in the east-west direction. Mainly, in the conditions considered for this simulation, which is without considering the canopy, the window-to-wall ratio for the top models is mainly 20 and in some cases 30.

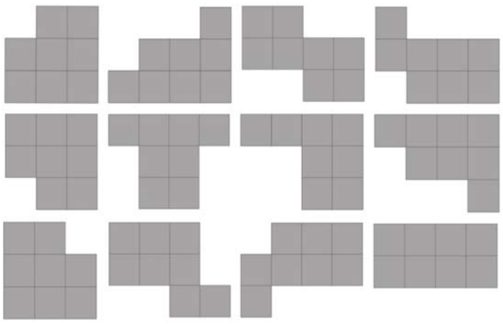

Figure 6. Forms with the lowest EUI in simulations

Figure 7 shows some of the forms that had the highest EUI. According to the image, the forms whose constituent cells have the most contact with the outside or generally have a linear arrangement or many breaks in the form are not suitable for this project. According to the results of this section, the forms that have the highest EUI mainly have a WWR of 40.

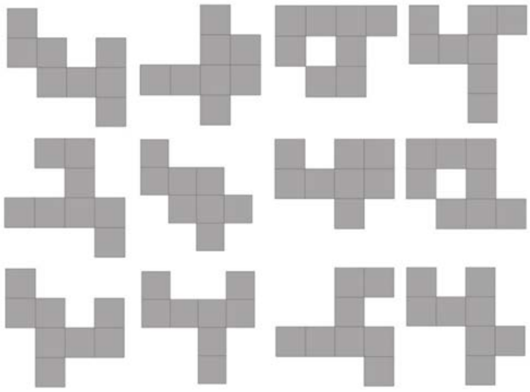

Figure 7. Forms with the highest EUI in simulations

In general, the lowest EUI of 93.18 and the highest EUI of 125.93 have been reported in this optimization, which indicates a difference of about 30% in the amount of energy consumption of different building geometries. This figure is very significant in the annual final energy consumption and considering the high volume of construction, which shows the high importance of paying attention to the geometry of the building in the early stages of design.

Regarding the validation of the results in the past years, several articles confirmed the validity of Honeybee and Ladybug plugins [13]. In addition to these articles, the results obtained in this study are consistent with the results of past studies regarding orientation, WWR, and optimal form in similar climates.

5. Conclusion

According to the topics discussed, optimizing the building geometry in the early stages of design can have a great impact on building energy consumption and improving thermal comfort. Based on the investigations carried out in the history of the subject, two different approaches to finding the optimal building geometry can be identified:

1. Pattern-oriented optimization
2. Computational optimization

In the past, due to the lack of appropriate and fast tools, the optimization of building geometry was based on patterns, and according to studies and reviews in this field, patterns have been recommended for similar climates. However, in this method, the different climates were not examined in detail and the difference in latitude or other environmental characteristics were not considered. On the contrary, in the calculation method that has recently received attention, with the help of modern tools, the optimization of the geometry will be evaluated more precisely in its climate and context. In the calculation method, designers can involve several factors in the optimization and include energy consumption reduction strategies such as using daylight or natural ventilation in the optimization process.

Therefore, in this research, taking into account that the study is carried out in the early stage of design and considering the speed factor, the most important parameters of building geometry, including form, orientation, and WWR as basic factors to reduce the energy consumption of the building, were optimized. In the form production process, the parametric method has been used to create modular forms so that, unlike the usual methods, all kinds of form combinations can be evaluated. In the energy simulation process of different building geometries, strategies such as natural ventilation and daylighting were applied. The results of this research indicate that the annual energy consumption can be reduced by about 30% with the decisions made regarding the general geometry of the building in the first stage of design. For the specified climate and building program, the most suitable form is more compact forms with 0 or 15-degree orientation and an opening percentage of about 20%.

In the future, by involving more variables through multi-objective optimization, as well as creating a comprehensive plugin, designers can be helped to make the right decisions in the early stages of design.

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