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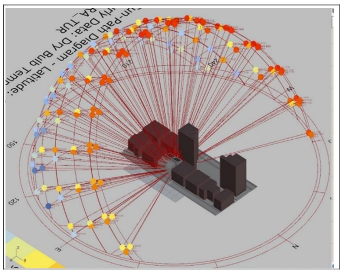

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DIGITILISATION IN SOLAR ARCHITECTURE COMPRESSED SHORTCUT (CS) TOOL USAGE, INVESTIGATION IN A RESIDENTIAL BUILDING IN ANKARA, TÜRKİYE

DIGITALIZACJA W ARCHITEKTURZE SOLARNEJ WYKORZYSTANIE NARZĘDZIA COMPRESSED SHORTCUT (CS), BADANIE W BUDYNKU MIESZKALNEGO W ANKARZE, TURCJA

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ABSTRACT

Solar-oriented architectural design is an emerging architectural approach to high energy consumption in buildings. The digital technologies used in this approach allow designers to test the performance of the building simultaneously by providing all the conditions of the design space parametrically. In this study, Compressed Shortcut (CS) tools, which are developed as an easy and fast solution to reach the optimum result in solar energy efficiency-oriented design approaches, are used. These tools are analyzed on a residential building in Ankara. Rhinoceros - Grasshopper and Ladybug plug-in programs were used as a method. As a result, the usability of the CS tools applied with the developed digital tools has been demonstrated as a method that enables the designs to be in optimum energy in a very fast and easy way.

Key words: Compressed Shortcut (CS) Tool, Digitalization, Solar-oriented design, Optimum energy.

1. INTRODUCTION

Due to its geographical location, Turkey has the potential to benefit from the sun much more than other European countries (Gülay, A. N. 2008). In Turkey, 82% of energy consumption in buildings is used in heating and cooling. This corresponds to 26% of the total energy consumed. In this context, it is important to maximize the benefit of solar radiation in the winter season, while preventing excessive heat gains in the summer season and ultimately providing optimum energy in the building envelope by means of digital technologies with decisions made at the early design stage. Within the scope of this study, a conceptual background on solar architecture and digitalization in architecture was created and Compressed Shortcut (CS) tools were developed using algorithms in Rhinoceros-Grasshopper software. Then, these tools will be analyzed in a case study on an residential building in Ankara.

1.1. Method and Tool

In the study, the digital technologies used for energy optimization in solar architecture and architecture are explained in detail based on internet databases, analyses and photographs to create the conceptual infrastructure.

The basic software chains were created with Rhinoceros Three Dimension (3D) based Grasshopper (algorithmic graphical editor) programme and Ladybug software. Ladybug software was used to define the simulation models and built environment parameters and to simulate energy in the models with EnergyPlus via Open Studio.

1.2. Significance of the Study

This study provides a method for designers to reach energy analyses easier and faster without the need for complex algorithm software in the urban built environment. At the same time, it is undeniable that the designs to be created with this method will make a great contribution to the country's economy as maximum gain will be achieved.

2. SOLAR ARCHITECTURE

The idea of utilising the sun in architecture has been experienced in pre-modern times, when access to electricity was inadequate. Today, this idea appears as a strategic phenomenon for energy saving (Yang, I. H., Nam, E. J. 2010). With the balanced use of factors such as solar lighting, heat gain and heat conservation in the design, indoor comfort can be provided, functional needs can be met and energy and construction cost levels can be minimised (El Sheikh, M. M. 2011). The sun, which is an important input in architectural design analysis, is an important factor in the formation and identity of the building envelope for energy conservation / gain by providing physical environmental comfort conditions. This identity is formed by determining how the building develops a style against the sun according to the climatic conditions of the building (Serraoui, M., Sellam, M. and Rebhi, M. 2016). The building envelope is a filter with adjustable gaps that prevents the undesirable effects of the sun, passes the heat flow, provides natural ventilation and allows cross ventilation when necessary. With its opaque and transparent components, it minimises the negative effects of climatic conditions and maximises the positive effects (Kiraz, F. 2003).

The shape of the building envelope, which has a great impact on energy performance, varies d pending on many criteria such as solar radiation and opening to the outside air, the location and climate data of the building, and also varies according to the volume of the building (Özmehmet, E. 2005). In order to provide comfort conditions in building interiors, it is important to determine the form of the building and the heat retention of the surface areas in order to determine heat losses and gains. Because the size of the surface area of the building is directly related to heat losses or gains as it also affects the building form. As the surface area of the building envelope increases, heat losses increase. For example, if one of the two different designs in the same volume has a geometric configuration with simple and narrow surfaces, the heat loss of this building envelope is low. Reducing energy loss by reducing the surface area in the form and utilising solar energy by opening large windows on the south façade is a good solution to provide optimum energy gain (Kuşçu, A.C. 2006).

The amount of energy of the sun's rays falling on an inclined surface at any location in the world varies according to the location, position and angle of incidence of the sun rays. Accordingly, it is possible to calculate the amount of solar energy by calculation or measurement devices (Duffie, J., A. and Beckman, W., A. 2013). The solar incidence angle is defined as the angle between the normal of the inclined surface hit by surface, ϴ z=0° and ϴ z=90° at sunrise and sunset (Fig. 1).

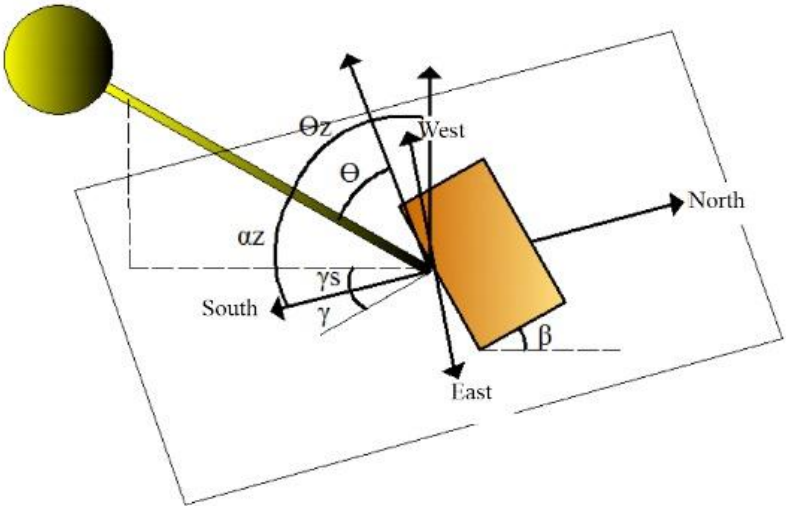

Fig. 1. Sun angles for an inclined surface. Source: Duffie, J., A. and Beckman, W., A. 2013.

Solar elevation angle (altitude) is the angle made by the direct sun rays (sun direction) with the horizontal. Solar azimuth angle (azimuth) is the angle made by the projection of direct sun rays on the horizontal surface with the south direction (Fig. 2).

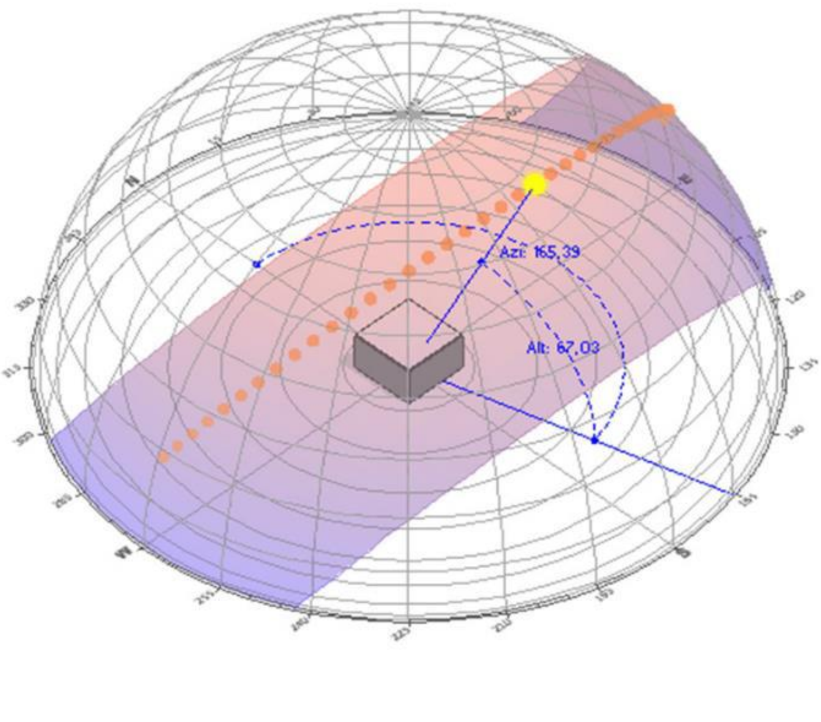

Fig. 2. Solar orientation diagram. Source: Serraoui, M., Sellam, M. and Rebhi, M. 2016. P. 48

Four important days, which are the beginning of the seasons, are caused by the rotation of the earth around the sun due to the tilt of the axis. 21 December and 21 June are called solstice (solstice), 21 March and 23 September are called equinox (equality of day and night). The date when the sun's rays come to the earth at the steepest angle is 21 June and the date when they come at the most oblique angle is 21 December (Fig.3).

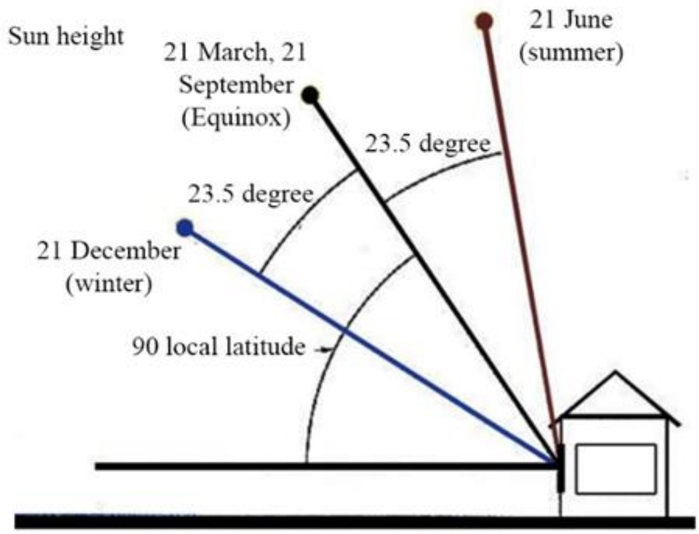

Fig. 3. Solstice - equinox angles (These angles apply to countries in the northern hemisphere). Source: Solstice

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While the amount of energy generated by the sun's rays falling on any area at a right angle is 40 Btu/ft², the amount of energy generated by the same amount of sunlight falling on the same area at an angle of 60 degrees is 27 Btu/ft² (Fig.4), (Anderson, K. 2014).

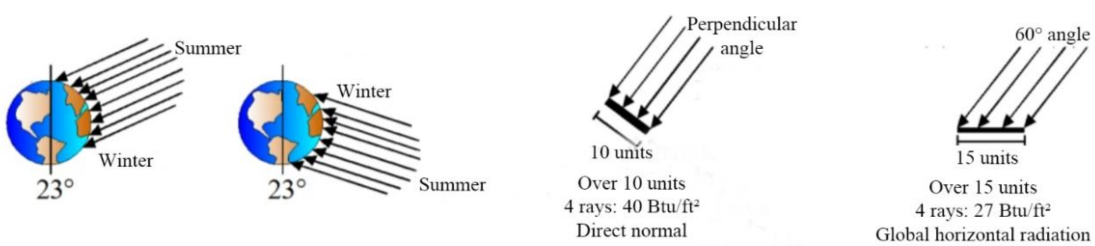


Fig. 4. The amount of energy formed according to the angle of incidence of daylight. Source: Anderson, K., 2014.

3. ALGORITHMIC SOFTWARE WITHIN THE FRAMEWORK OF DIGITAL TECHNOLOGIES IN ENERGY OPTIMISATION IN ARCHITECTURE

Within the framework of digital design, algorithmic and Building Information Modelling (BIM) - related energy-oriented design tools, Revit - Dynamo and Rhinoceros - Grasshopper programmes, which are the most preferred software in today's architectural environment, are examined in detail:

3.1. Autodesk Revit and Dynamo

Among the BIM programmes, Revit is the most prominent software for performance-based design depending on algorithmic parameters. In the models worked with Revit, it is possible to obtain data on the building in every process from the beginning of the design. Unlike other CAD and ICM programmes, it is possible to work with more than one user and the process can be managed with project coordination (Kim, M., Kirby, L. and Krygiel, E. 2016). Figure 5 shows an example of a parametric model made in Revit programme (Kensek, K., M. 2014).

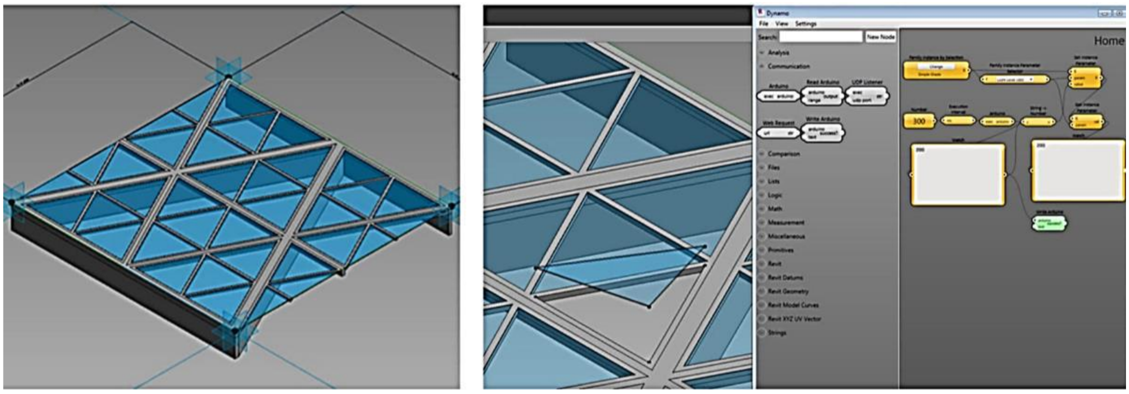


Fig. 5. Revit parametric modelling example. Source: Kensek, K., M. 2014. P 6

Dynamo, on the other hand, can be used as a stand-alone programme under the name Dynamo Studio, but it also serves as an add-on software to the Revit programme. The geometry and data produced with Dynamo are formed by the simultaneous interaction of files called families with node-based diagrams. Graphical elements called nodes with data input and data output can be used without the need for code software. In Figure 6, the data coming out of the output part of the nodes are connected to the input part of another node using wires and the final product is reached by this means (Mousadais, T. and Mengana, S. 2016).

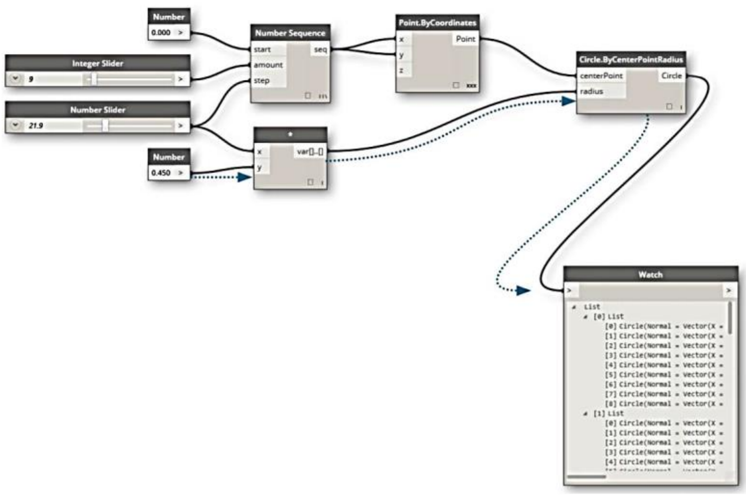


Fig. 6. Example of Dynamo's programme flow. Source: Mousadais, T. and Mengana, S. 2016. P 19

3.2. Rhinoceros and Grasshopper

Rhinoceros is a 3D modelling program developed by Robert McNeel and Associates with a wide range of applications such as jeweler design, car design, marine design, mechanics, model production, engineering, multimedia and graphic design. Important features of the Rhinoceros programme are listed below:
- It is a set of tools using 3D modelling techniques aiming to be shaped freely and with the desired freedom.
- It can be used in precise dimensions in design, analysis, engineering, document and production areas.
- Since it is a professional software in its field, error-free data is provided in large projects in an extremely comfortable way.
- It has a format that is compatible with analysis, animation, visualization and illustration programs and can provide transition to these programs.
- It supports 3D scanners, 3D printers and 3D digital tools and provides error-free data (Suyoto, W. Indraprastha, A. and Purbo, H. 2015).

Grasshopper is a programming software developed by David Rutten and used as an add-on to Rhinoceros. Thanks to the algorithmic components it contains, it allows real-time adjustment of the design features and variable values (Villamil, A. A. G. 2014). Grasshopper utilizes algorithmic connections while offering these opportunities to users. In order for these connections to be properly executed, the outputs must be obtained with correctly defined steps. Regardless of complexity, all algorithmic solutions have three building blocks: input, key processing and output. In the input part, data is input, the key processing part consists of algorithmic steps that define the design process, and the output part provides data output (Fig.7), (Issa, R. 2020).

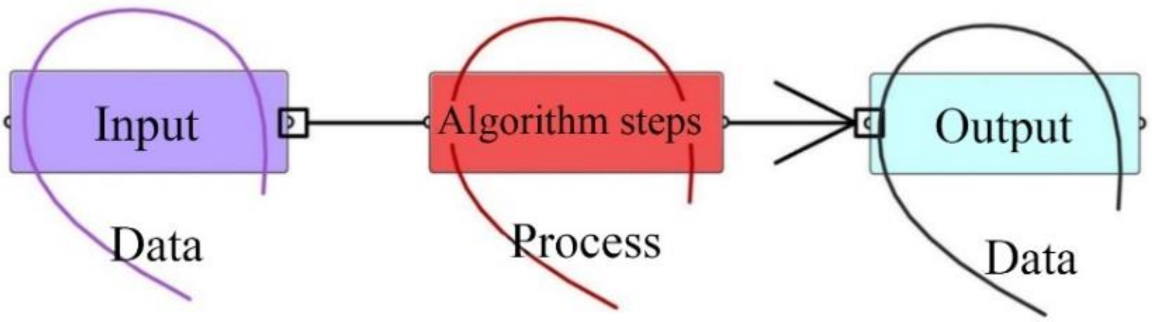


Fig.7. Building blocks of algorithmic solutions in Grasshopper. Source: Issa, R. 2020. P 5

Among parametric programmes, Rhinoceros differs from others with some features. Designers use this programme in the formation of complex forms and shapes, and they have the chance to intervene in their designs easily by changing the parameters with the Grasshopper plug-in programme. The Rhinoceros programme, which works at extremely precise dimensions, differs from programmes such as 3D Max, which is based on mesh (lattice in mesh modelling), by being Non-Uniform B-Splines (NURBS) based (Fig. 8), (Pak, B. 2003).

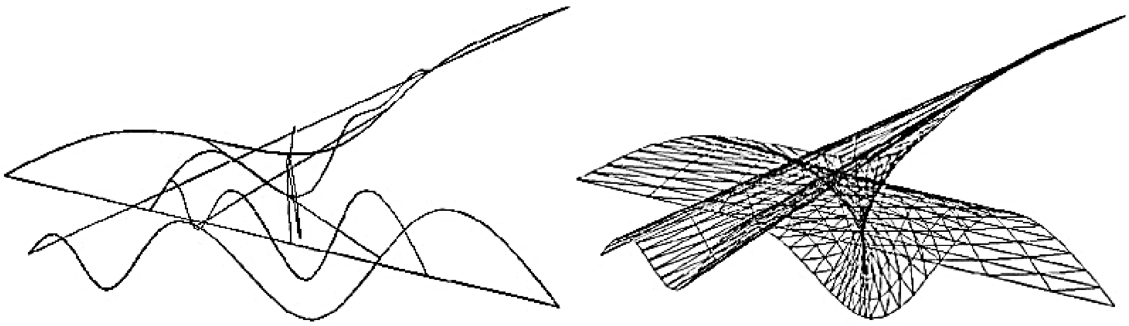


Fig. 8. Representation of a 3D surface with NURBS and mesh - wireframe models. Source: Pak, B. 2003. P 42

In fact, many non-parametric and parametric design programmes used for presentation and animation purposes can be analyzed with plug-in software called ‘plug-in’. However, it is possible to obtain the desired data by modelling in one of these programs and transferring it to another analysis program. However, at this transfer stage, some deficiencies and errors may occur due to the change of format.

In order to avoid all these problems, all desired data such as environmental analyses, structure, material analyses can be obtained with the Grasshopper software, which is an add-on to the Rhinoceros 3D program, which can meet all needs and is specialized in this field (Yazar, T. and Uysal, S. 2016), (Tab. 1).

Tab.1. Some of the plug-in programmes used for environmental, structural and material analyses in Rhinoceros – Grasshopper. Source: Yazar, T. and Uysal, S. 2003.

The Programme	Rhinoceros plug-in programme	Some of the Grasshopper plug-in programmes	
Rhinoceros	Grasshopper		
Rhinoceros NURBS modeling for Windows		Ladybug	Kangaroo
		Honeybee	Karamba 3D parametric engineering Karamba
		Heliotrope	BullAnt
		Geco	Hummingbird
		Gerilla	Mantis
		Diva	ArhSim

Among all these add-on programmes that can be used in Rhinoceros, seven tools, namely Ladybug, Honeybee, Heliotrope, Geco, Guerrilla, Diva, are currently the most commonly used tools for environmental analysis.

4. AN ARCHITECTURAL DIGITAL TECHNOLOGY: THE COMPRESSED SHORTCUT (CS) TOOL, INVESTIGATION IN A RESIDENTIAL BUILDING IN ANKARA, TURKEY

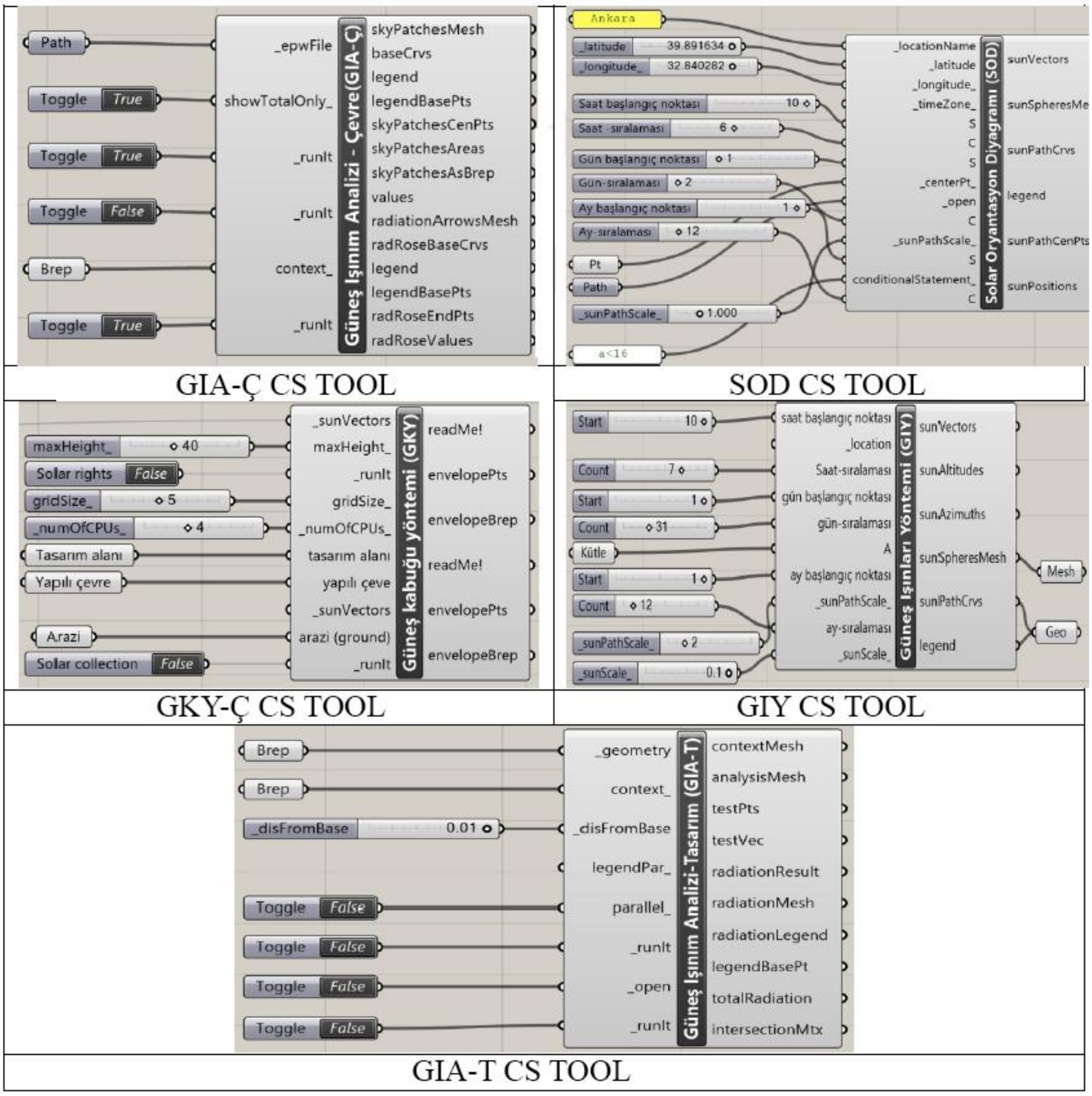
By using environmental analysis plug-ins, a tool that reaches the optimum energy quickly and easily has been developed.

4.1. The Compressed Shortcut (Cs) Tool

The CS tool covers the creation of compressed shortcut tools in order to easily transfer the design approaches for maximum solar utilization and sun protection, when necessary, in the context of energy efficiency to the design process, to increase the usability by eliminating the complex processes of the programmes that can be used in this process and to shorten the possible time to be spent. While implementing energy efficiency-oriented design approaches, designers have a number of expectations and criteria in terms of performance. These criteria change for each design area with the interaction of the sun and the design area depending on the coordinates where the design is located. In order to make designs suitable for each location, algorithmic connections should be established through technological tools related to environmental parameters depending on the design area and the environment where the building is located. Among these tools, the Rhinoceros add-on programme Grasshopper and the Ladybug software running under this programme were selected as the most basic programmes in the stage of realizing the proposed design process.

Grasshopper works with NURBS (Non-Uniform BSplines) surface logic, which is not very advanced in other programmes. In other programmes, complex geometry generation is limited. However, in this study, since the sun rays are taken into account while creating the design boundary, it is possible to have complex geometries of the shell. At the same time, the programme works with precise and exact values and there is an opportunity to intervene in the designs easily by changing the parameters. The use of more than one programme for design and simulation not only slows down the process, but also causes some problems such as data loss as the model and different interfaces work together. In Grasshopper, modelling and energy calculations can be done in the same interface. These criteria were effective in selecting Grasshopper as the most suitable programme for the study and CS tools were developed. The developed CS tools are given in the Tab.2.

Tab.2. CS Tools developed for optimum energy, Source: creating by the author.



4.2. Case Study: Analyzing CS Tools on Residential Building In Ankara

The residential building located in Harbiye district of Çankaya district of Ankara province was modelled with its surroundings through Rhinoceros software to determine the parameters of the CS design tool to be applied and defined on Grasshopper software for climate analysis.

When we look at the immediate surroundings of the selected residential building, it is seen that it is surrounded by other 4-storey residential buildings and a 4-storey government institution building. On the other hand, there is a 17-storey residential block immediately behind the residential building to be analyzed (Fig.9).

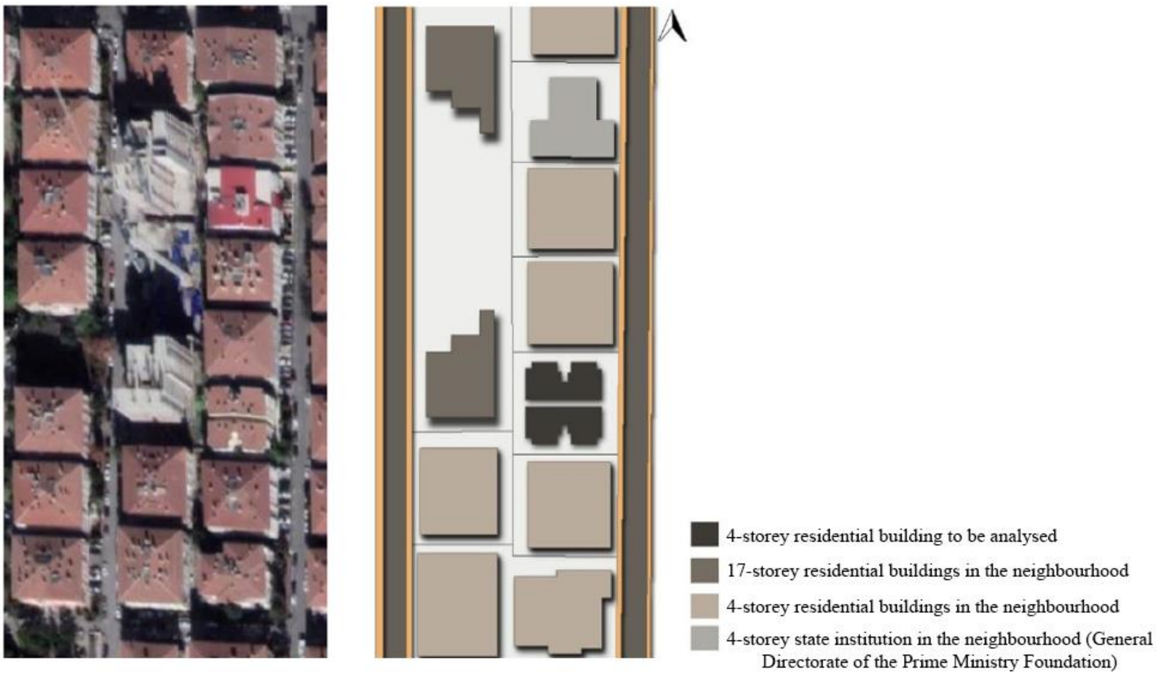


Fig. 9. Site plan of the built environment where the design area is located, Source: preparing by the author.

The selected residential building consists of 4 storeys with four symmetrical flats on each floor (Fig.10). The building is shaped in a square form in both North-South and East-West directions due to the limited data of the land on which it is located. Each flat consists of a kitchen, a living room, three bedrooms, an entrance hall, a corridor and two wet rooms (WC and bathroom).

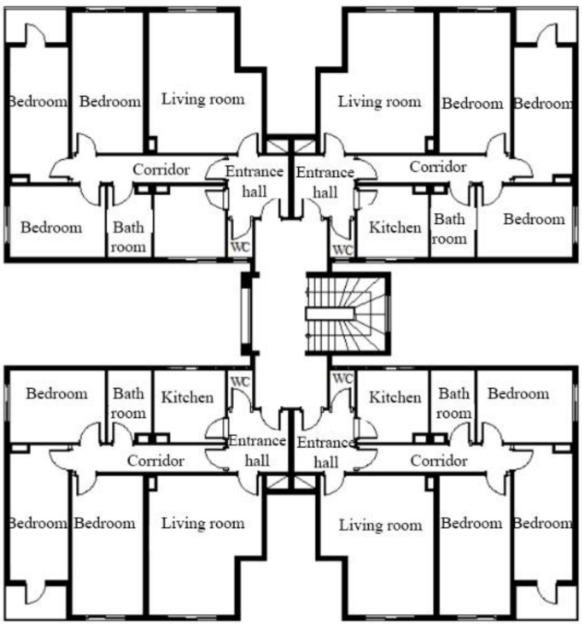


Fig. 10. Normal floor plan of the selected residential building, Source: Soytürk, H. 2019, Architectural Project Data

4.2. Steps of Use of the CS Tool and Analyses of the Building

For the CS tool to be applied on the residential building located in Harbiye district of Ankara province, the area was first modelled with its surroundings through Rhinoceros software and defined for radiation analysis on Grasshopper software (Fig.11).

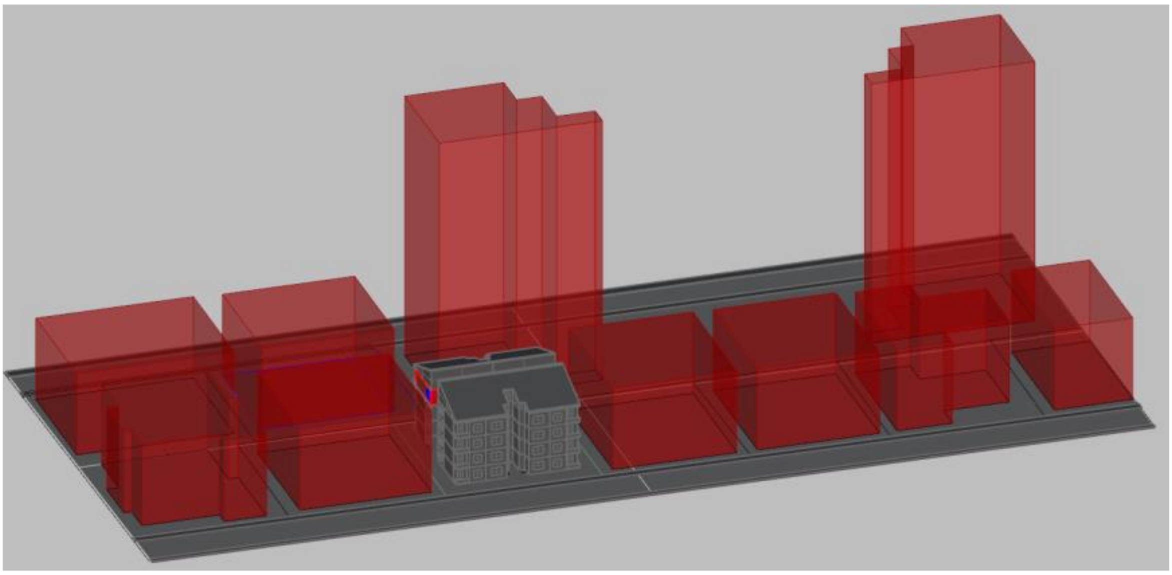


Fig.11. Residential structure and its surroundings defined on Grasshopper software, Source: creating by the author

In the solar radiation analysis with the developed CS tool, it is seen that this block blocks the western sun coming to the residence and only a small amount of western sun comes from the southwest direction (the area between these two models). There is an increasing insolation rate from the north-east to the south of the residential building. The maximum insolation rate is in the southeast direction and the insolation rate is minimum in the north of the residential building (Fig.12).

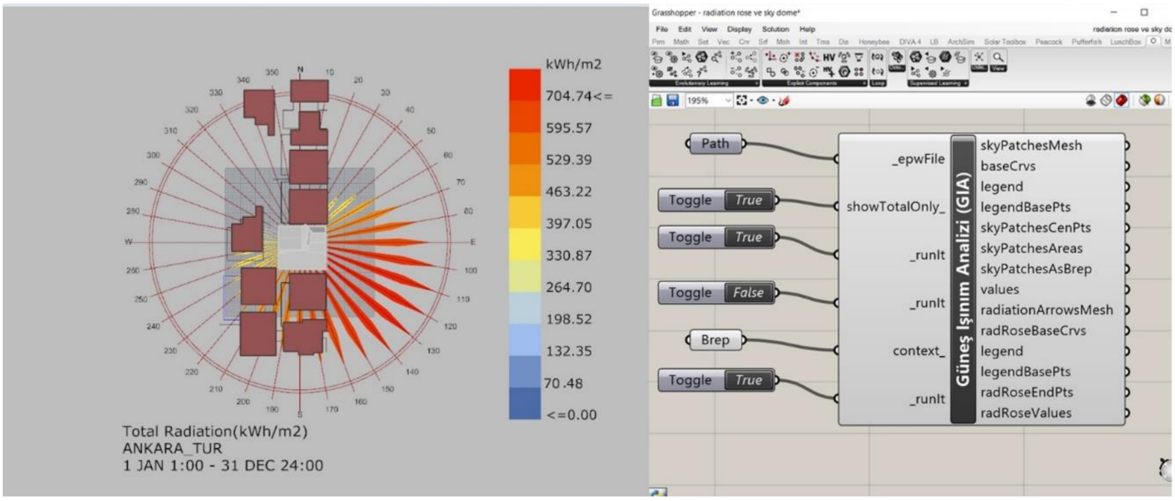


Fig.12. Annual solar radiation amount by Radiation rose analysis with the developed CS tool, Source: creating by the author

Then, the developed CS tool solar orientation diagram was made (Fig.13).

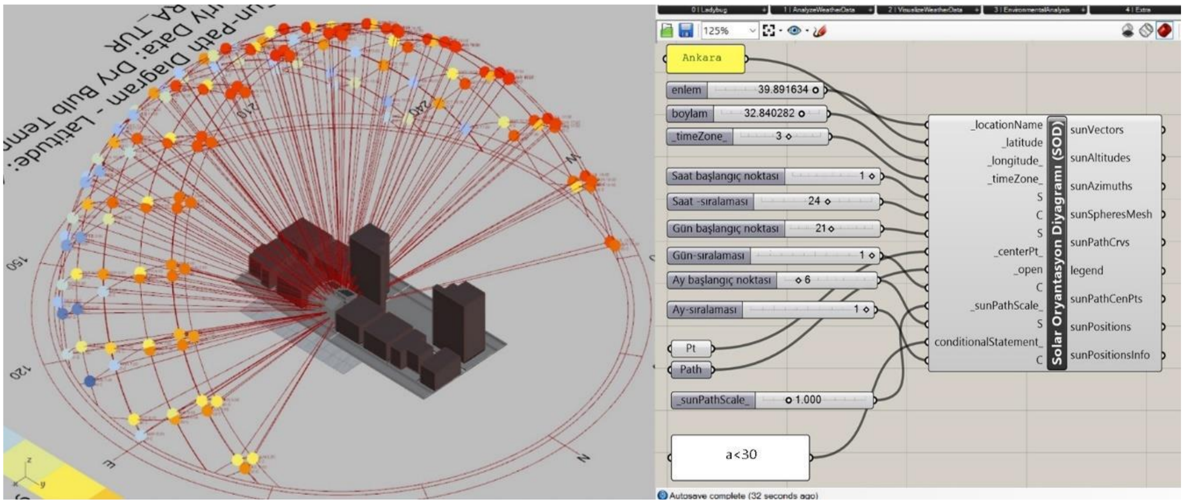


Fig.13. Solar Orientation Diagram (SOD) generation with CS tool, Source: creating by the author

Then, by means of the developed CS tool, the irradiance amounts became visible in the Rhinoceros interface. It is possible to say that the residential building has maximum solar radiation in the east direction and minimum solar radiation in the west, north and south directions (Fig.14.).

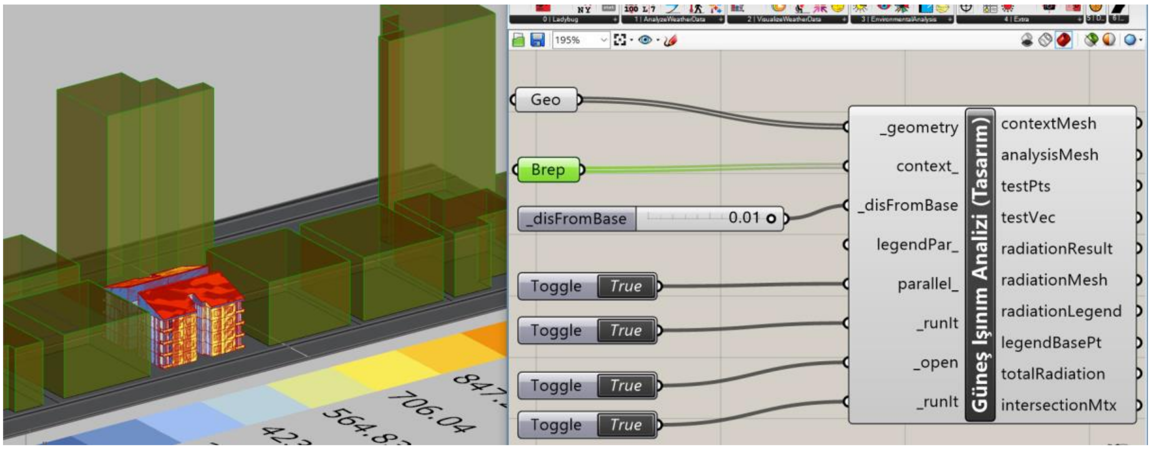


Fig.14. The annual amount of solar radiation falling on the building envelope (North, south and west facade), Source: creating by the author

While the highest value of the total radiation is 1412,09 kWh/m², the lowest value is 141,21 kWh/m². The monthly heating energy use of the residential building is 134,43 kWh/m² while the cooling energy use is 22,25 kWh/m² (Fig.13). According to these data, it is understood that many design concepts of the residential building, from the design phase to the material selection, are not suitable for the direction and amount of solar radiation.

4. DISCUSSION

In the design area selected within the scope of the case study, the annual solar radiation amounts of the residential building were analyzed by means of CS tools. The annual solar radiation amount of the residential building is 141,21- 1412,09 kWh/m².

In the solar radiation analysis carried out quickly with the CS tool, it was observed that the radiation is not evenly distributed on the facades of the residential building due to the effects of the built environment. The 17-storey high residential block located to the west of the dwelling blocks the western sun coming to the dwelling. However, there is also a minimum amount of solar radiation on the north façade of the dwelling.

This leads to maximum heating energy use of the building. The monthly heating energy use of the residential building is 134.43 kWh/m² while the cooling energy use is 22.25 kWh/m². With CS tools, these results were obtained easily and quickly with just a 'run' algorithm.

6. CONCLUSIONS

The sun has the highest potential among renewable energy sources in Turkey. Because Turkey is located in the so-called sun belt. Maximum efficiency in terms of energy can be obtained by using different methods in designs focused on solar rays. In this context, it is necessary to provide maximum benefit from the sun's rays in the winter season, while preventing excessive heat gains in the summer season and ultimately providing optimum energy in the building envelope through the digital technologies used in this context.

In solar architecture, since the sun is a parametric phenomenon, parametric designs and the technologies used in creating these designs are important. In this study, Rhinoceros-Grasshopper programme was selected among these technologies. With this program and Ladybug plug-in, CS tools have been developed that can perform energy analyses very quickly and easily.

Apart from the analyses of existing buildings, the use of CS tool in new designs is of great importance in terms of energy efficient building design. By using this tool, the energy efficiency of buildings can be questioned in a very short and easy way and optimum energy designs can be made. It is thought that this situation can constitute an important approach and thus a great contribution will be made to the national economy.

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AUTHORS NOTE

This study is produced from the doctoral thesis completed in 2020 by Meryem Alagöz Konur under the supervision of Figen Beyhan. In this study, a new design method is proposed for the buildings designed in built environments to benefit from the sun at the maximum level in the context of neighbourhood relations and also for optimum protection from the sun in the desired areas of the buildings, and algorithmic Compressed Shortcut tools (CS) have been developed to complete this method in the fastest and easiest way without establishing complex algorithmic connections. The CS tool was completed through Rhinoceros - Grasshopper and Ladybug, ArchSim, Diva plug-in programs. Among the existing design methods compared with the fuzzy logic technique, it was determined that the Solar Rays Method is the most suitable method that can easily reach the optimum solution for the proposed method. In the proposed method, a new optimum guideline design limit is reached by using the Solar Shell and Solar Rays Methods together and all the steps to reach this limit are realized by means of the developed CS tools.

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