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Analysis Of Solar Radiation Towards Optimization and Location Of The Urban Blocks In The Neighborhood Units

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Abstract

Increasing population causes Energy consumption and environmental pollution. It is essential to consider renewable forms of energy, especially solar power, to reduce energy consumption. This requires attention to energy issues in the early stages of urban design and practical and creative solutions for more efficient use of this type of energy. This study aims at calculating the annual solar radiation at a city scale through a novel process and methodology. In this regard, artificial intelligence algorithms and satellite data can help maximize the amount of sunlight in neighborhoods and urban blocks in neighborhood units during the development process. In the simulation process, location, and optimization of the urban form, it is necessary to consider the limitations and resources for field study and simulation of urban blocks. Therefore, in this study, Farhangian neighborhood in phase 1 of Kermanshah, Iran, which has a good level of structural diversity and lends itself to field studies, was selected and studied at neighborhood and urban block scales. The case study indicates the significant role of calculating and optimizing the patterns of urban blocks to achieve maximum solar energy. Estimates at different levels show that urban block variables effectively access solar radiation energy and, given various scales of development - from macro-scale spatial planning to micro-scale local design - can improve energy intake by 3 to 5 percent. Accordingly, the results show that to accelerate the calculation of energy at the planning scale, the use of 2.5D locating model and 3D optimization contribute to achieving the maximum or minimum solar radiation, respectively. On the other hand, this method can be used to organize calculations and planning for maximum absorption of solar radiation at different stages of development.

Keywords

Urban Morphology, Solar Radiation, Optimization, Parametric Design, GIS, Ladybug;

1. Introduction

Efficient energy planning and design denote the relationship between land use and building design. Principles of efficient energy planning involve the systematic examination of the city in terms of three scales, i.e., settlement characteristics, building block characteristics, and building characteristics when deciding on land use. Therefore, it is necessary to consider ideas for mitigating the effects of climate change and ensuring the efficient and effective use of energy (Mert & Saygın, 2016). The related literature shows that urban geometry and energy consumption are closely related. In this regard, previous studies have examined in detail the relationship between urban morphological parameters and the theoretical energy efficiency and energy heat generated by the spatial configuration of cities. A common theme in global approaches to the city and energy revolves around the sun's potential as the most significant energy source available to all urban areas(Amado et al., 2016).

The process of energy efficiency or, more broadly, improving the sustainability of building quota is not just a matter of technology optimization but also involves decision-makers, investors, and citizens. To promote and regulate such a large and complex process in renovation projects, local authorities, i.e., decision-makers, must have the required knowledge and tools to design plans or programs that integrate the energy model into more comprehensive approaches to urban renovation(Pili et al., 2018). In addition, the analysis of constraints on an urban scale makes it possible to determine more realistically the solar potential of construction surfaces. However, the studies of typological factors and their sensitivity and relationship with solar technology can lead to different interpretations by introducing weight indicators for different geometry, typology, and construction constraints that affect the integrity of the solar energy system. Despite using solar energy in cities to create sustainability in housing facilities, there is no related commitment in construction. Similarly, the amount of solar radiation is usually not taken into account in urban planning decisions. It is essential to know the solar radiation levels reaching those parts of the building used to install solar panels or heat collectors to formulate energy efficiency measures in new buildings (Fernández-Ahumada et al., 2019).

The methods and tools used in the initial design phase should support architects and planners in decisions leading to solar buildings and help further develop and evaluate various solar technologies in the construction phase(Horvat & Wall, 2012). Tool constraints include model configuration and model simulation time for urban projects indicating the need for different solutions and simplifications to increase the speed and accuracy of such models(Dogan, 2015). Urban morphology significantly impacts solar potential, daylight, and natural ventilation. Hence, comprehensive planning largely determines the inherent environmental performance and its blocks. Architectural and urban planners should develop a wide range of related guidelines and simulations in their design process. This parametric study, performed by simulation tools in a process-oriented approach at two different scales, is probably the first step to this end because it analyzes the different types of morphological structure and urban blocks and their potential contribution to locally produced energy. This study seeks to find a comprehensive solution to quantify the role of solar energy as a source of renewable energy in various urban morphologies. In addition, it investigates the possibility of achieving the maximum amount of solar radiation through the use of the 2.5D measurement method and three-dimensional data, especially data on the urban block scale and a combination of these two data types.

2. Background

Urban areas have expanded widely in recent decades, and the rise will probably continue in the coming decades. Many countries provide excellent opportunities for local generation and energy use, thereby minimizing energy loss or transfer(Mohajeri et al., 2016). Typology is a tool admired by urban designers. Mapping the future of cities in Europe from the late 1960s to the 1970s encouraged Krier(Krier, 1978) to use typological studies to guide design, reintegrate fragmented parts of the town, and emulate the best pre-industrial cities. However, as people's lifestyle changes much more dramatically than in the past, the typology of the city will no longer host it forever, and the elements of the urban form are constantly changing and getting replaced. Thus, new typologies emerge, reflecting people's unique lifestyles, though not entirely invented. On the other hand, the building plan usually determines the activities and programs inside the building. After decades of implementation and critique of zoning, the mixed-use approach has become a common strategy for programs on a regional scale (Shi et al., 2017). These forms should be considered in line with climate programs and part of a long-term plan based on environmental needs.

Using the 3D model for analyzing solar radiation due to different limitations, such as large scales and solar direct radiation in urban areas, is always not possible. Also, selecting an algorithm for calculating solar radiation by comparing different models is possible, Because computational algorithms adopt different models of sky vision and sources for climate data(Noorian et al., 2008). In some cases, the researcher utilizes small-scale analysis and statistical models. While others compare the results provided by more well-known tools for urban-scale solar analysis or with more accurate calculations performed by software for building-level dynamic solar analysis. Computational time and activities, the demand for setting up basic data, and interpreting results are some of the critical issues that can limit the application of these models in areas with high economic and human resources. Building energy performance is influenced by urban geometry, building design, Systems efficiency, and Residents' behavior. Also, these factors are under the control of various actors in the construction sector: urban planners and designers, architects, and system engineers(Ratti et al., 2005). Thus, the calculation in different scales of the cities is divided into three scales: small Scale, middle Scale, and macro Scale.

2.1. Solar energy modeling methods on the macro Scale

In this framework, developing a comprehensive urban planning process based on solar energy and its composition in an urban area is called solar urban planning(Amado & Poggi, 2012). This approach is used by a variety of planning methods that support the use of solar potential as a significant urban design issue to improve energy supply and productivity in existing urban areas and to promote integrated photovoltaic building (BIPV) in new cases(Amado & Poggi, 2012; Lobaccaro & Frontini, 2014). Predicting the right location for photovoltaic systems on buildings and providing their potential energy is essential in supporting solar urban planning methods(Gadsden et al., 2003). Therefore, the framework encompasses a combination of technological and strategic solutions that contribute to energy efficiency at the local level if they are still sufficiently organized to deal with the city's conception, development, and management. The energy efficiency challenge requires the development of urban models that lead to energy savings and the installation of photovoltaic systems with the parallel integration of smart grids to develop a framework beyond the single building (Amado & Poggi, 2014a). In this case, energy efficiency involves changes on a much longer scale. A new study by Amado and Poggi (2014b) suggests that urban cells should be considered for automated urban planning based on the concept of Automata Cellular (CA). They offer an approach to discovering the potential of photovoltaic solar power in cities that are divided into urban units by region and neighborhood(Amado & Poggi, 2014a).

In this approach are the scientific perspectives of CA models developed to analyze various aspects of macro-spatial urban development, such as city shape, city size distribution, and population density, which include a set of intertwined methods and tools. So, using these analytical approaches in the urban system, the relationship between solar potential and energy consumption patterns can be effectively investigated, and urban parameters can be turned into a field of urban readjustment(Besussi et al., 2010). The concept of parametric models emerged in the second half of the 1990s in technological and computer-aided models, which originated from the development of software created to construct buildings in a digital environment. This generation of new tools, called building information modeling or BIM, is basically based on the process of producing and managing all information related to buildings in different phases of design, project, construction, and user usage period. Recently, the parametric approach introduced by BIM in the architecture industry has been experimentally used on an urban scale(Eastman et al., 2011)

Urban form is a determining factor for the energy efficiency of a city. In a review, Abd Alla et al. introduced an approach to improve renewable energy technologies' resources in municipal planning and to review urban management policies to strengthen their effectiveness. The analysis emphasizes the potential of solar energy and the local energy needs of the city. It uses an analytical method based on the facades of existing buildings to convert them into GIS maps, making it possible to identify areas where investment and unique technology are more efficient(Abd Alla et al., 2020). In another study, Amado et al. used redesign of urban areas and planning of different regions through a cellular model to investigate the energy consumption and solar energy supply with urban morphology parameters and their relationship with electricity consumption. The purpose of the study was to provide a detailed framework of urban planning guidelines to support the optimization, adaptation, and development of energy-efficient cities(Amado et al., 2016).

Another study by Chen and Norford investigated five simple indicators covering three performance areas, i.e., solar, ventilation, and connectivity potentials. Based on two different geometry types, the study showed that geometric data changes could be used to obtain the appropriate urban form to optimize the data. Finally, these indicators were developed in the open-source library of Pyliburo in Python, accessible for designers and researchers to be used in their existing design workflows(K. W. Chen & L. Norford, 2017). On the other hand, three-dimensional solar radiation models are needed to facilitate the interactive evaluation of photovoltaic potential in complex urban environments. SURFSUN3D is a visualization-oriented full 3D solar radiation model used by Liang et al., who introduced a framework for integrating SURFSUN3D in a 3D GIS-based application for interactive evaluation of photovoltaic potential in urban areas to achieve efficient calculations and visualization for 3D urban models(Liang et al., 2014).

Recent efforts have been made to integrate energy considerations into urban planning and design using artificial intelligence(Rahbar et al., 2020). the research introduced by Lila et al., the adaptation and development of an open-source Artificial Neural Network (ANN) with the aim of predicting solar radiation for newly generated neighborhoods in Aswan, Egypt, as an example of a hot arid zone. The outcomes are the result of training the ANN on a database of classified urban geometries and their solar radiation simulation results for local weather conditions(Lila et al., 2021). To sum up, the researcher will be investigated to find the integrated result to calculate solar radiation and overcome the constraints of the city and its issues.

2.2. Solar energy modeling methods on the mesoscale

Solar radiation models are used to estimate solar radiation collection at a location on Earth. Most existing models do not typically consider the effects of urban shading. Universal radiation received at a point and in a specific period of time consists of direct radiation, scattered radiation, and reflected radiation. In most cases, the reflected radiation is negligible, and we can ignore them (Fu & Rich, 2000). Solar maps support the localization of the most suitable building surfaces to predict solar system installations and make it possible to minimize the potential for solar energy harvesting. Most cities have implemented online solar maps that provide information on the potential of solar energy and generation on the roofs of existing buildings. But some examples consider the solar potential of planned buildings(Wall et al., 2017). One of the major research gaps associated with existing solar maps is that most maps related to solar potential estimation are available for small-scale roof installations but are not available for integrated solar facade systems (Lobaccaro et al., 2012).

Most solar maps analyzed based on geometric data (ie buildings, lands, vegetation) are formed by Light Detection and Ranging (LiDAR) data. 3D information focuses on radiation analysis and energy production by photovoltaic (PV) systems, although solar thermal output (ST) is sometimes available (Kanters, Wall, et al., 2014). So, the best solution for solving this problem is using remote sensing and 3D form to analyze solar radiation. Many researchers investigated how to calculate solar radiation by remote sensing(S. Zhang et al., 2019) and 3D form in an urban area and urban blocks (Shakibamanesh & Veisi, 2021). The concept of form-based code is of fundamental importance in modern American urban planning. Hence, parametric thinking is used in evaluating form-based code scenarios(Zhang & Schnabel, 2018). Other studies by Zhang et al. investigated the context of urban environmental morphology via parametric thinking. Studies have shown that parametric techniques can effectively simulate the urban morphology of the environment by producing parametric models. The findings also include a critique of parametric thinking applied in urban environments and insights into the potential applications of parametric techniques to support quality environmental urban morphology(Zhang & Liu, 2021).

In another study, urban building energy modeling (UBEM) was used to evaluate the strategies for optimizing the use of building energy to support the building energy goals of a city. The study covered 16 single-family buildings, 16 multi-family buildings, and 14 office buildings. Results showed that the standards of prototype building specifications, building dataset, and workflow could be used to create other building prototypes and to support the energy efficiency of the Italian national goals for building and environmental protection(Carnieletto et al., 2021). Several studies at urban block scale have been carried out (Vermeulen et al., 2015; Vermeulen et al., 2018). In a study conducted by Yi and Kim on the building Scale, the need for specific building codes for each building form in neighborhoods was stressed and deemed as the basis for the right of access to sunlight (Yi & Kim, 2015). On the other hand, an analysis based on the typology of urban patterns aimed at investigating daylight showed that choosing a specific typology could contribute up to 16% of total energy performance and up to 48% of sunlight in buildings with similar urban density(Sattrup & Strømann-Andersen, 2013).

2.3. Solar energy modeling methods in the microscale

Due to the high demand for monitoring the energy performance of buildings, evidence-based design becomes more important for all actors in the design process, especially in the municipality and city council, by validating various design options and selecting the most appropriate options from all points of view. he does(Kanters, Horvat, et al., 2014). It is generally acknowledged that up to 80% of design decisions affecting the energy performance of a building are made at the initial design stage, which is where architects play a dominant role. The design and management of distributed solar in buildings involve multidisciplinary stakeholders with diverse aims and objectives, ranging from acquiring architectural visual effects to maximizing solar insolation at a given location, maximizing energy generation, and minimizing operation and maintenance costs. Wijeratne analyzed the characteristics of 23 solar PV design and management software and four smartphone/tablet apps against 15 important criteria of solar PV design. The findings indicate that the chosen PV design and management tools cannot meet all PV design and management requirements(Wijeratne et al., 2019).

An international survey of architects on solar design tools and methods found that one of the obstacles for architects to engage in solar design is that some are unaware of the principles of solar design and the capabilities of existing solar design tools. Research shows that solar design, the principle of passive solar design and active harvesting of solar energy, is not part of the core curriculum in some areas. This may soon be a problem, as in some municipalities/regions/countries, most of Europe, some of the energy needed to operate the building must come from renewable sources. Therefore, architects will soon be faced with the fact that they must be actively involved in this aspect of design(Wall et al., 2017).

Reports from the Subtask B subset show that there is a wide range of digital tools that architects use today(Kanters, Horvat, et al., 2014). Although these digital tools can be classified into three main categories (CAAD tools, visualization tools, and simulation tools), only some CAAD tools and simulation tools can be used for solar design at the initial design stage. Thus, analyzing solar radiation need special software based on different scale. In general, studies at different urban scales can be divided into three categories i.e., microscale studies, which cover regions, and cities; mesoscale, such as sub-neighborhoods neighborhood units, and urban blocks and macro-scale studies, which include urban neighborhoods. On a small scale, when architects face a high-rise building or a home, they can handle a wide range of software. But when urban planners, policymakers, and urban designers need limited information for designing or planning, they need to develop a methodology for analyzing different types of energy. General studies in this area are summarized in Table1.

Table 1. Studies on urban structure and solar energy intake

Data Scale	Title	Method / Algorithm	Tools	Source
Micro Scale: Building	Genetic-algorithm based approach to optimize building envelope design for residential buildings	Genetic algorithm	Matlab	(Tuhus-Dubrow et al., 2010)
	Solar energy potential on roofs and facades in an urban landscape	Algorithm SOL LiDAR data	GRASS r.sun	(Redweik et al., 2013)
	Parametric study of URBAN morphology on building solar energy potential in Singapore context	Parametric	-	(Poon et al., 2020)
	Performance-driven optimization of urban open space configuration in the cold-winter and hot-summer region of China	Optimization genetic algorithm	Grasshopper	(Xu et al., 2019)
	From solar constraints to urban design opportunities: Optimization of built form typologies in a Brazilian tropical city	Multi-objective optimization NSGA-II	Citysim	(Martins et al., 2014)

Table 1 Continued

Middle Scale: Urban _block	The effect of urban morphology on the solar capacity of three-dimensional cities	-	Sun Position	(Zhu et al., 2020)
	Impact of urban block typology on building solar potential and energy use efficiency in tropical high-density City	Geometric parameters	Rhinoceros3D Ladybug Honeybee Radiance Energy plus	(J. Zhang et al., 2019)
	A Cellular Approach to Net-Zero Energy Cities	Geographical Urban Units Delimitation Parametric Modelling	ArcGIS Rhinoceros3D Grasshopper DIVA	(Amado et al., 2017)
	Periodic urban models for optimization of passive solar irradiation	Evolutionary Algorithms	ENVI-MET	(Vermeulen et al., 2018)
Macro Scale: Urban _Neighborhood, City	A review of simulation-based urban form generation and optimization for energy-driven urban design	Differential evolution	City Energy Analyst (CEA)	(Shi et al., 2017)
	Solar energy and urban morphology: Scenarios for increasing the renewable energy potential of neighborhoods in London	The generic models for this simulation	ArcGIS ArcMap	(Sarralde et al., 2015)
	Evolutionary algorithms for generating urban morphology: Variations and multiple objectives	Pareto Evolutionary Algorithm 2 (SPEA-2)	Octopus Grasshopper 3D	(Makki et al., 2019)
	Evaluating Urban Forms for Comparison Studies in the Massing Design Stage	Identification and Application of the Performance Indicators	Python ، Pyliburo	(K. Chen & L. Norford, 2017)
	A Methodological Analysis Approach to Assess Solar Energy Potential at the Neighborhood Scale	Dayism-based hourly method Cumulative sky method simulation modeling, analysis, and processing tools	Rhinoceros3D Grasshopper Honeybee DIVA Revit	(Lobaccaro et al., 2019)

The gaps between research and methods are related to the calculation of Solar Radiation on different scales. Studies show that the most common calculation methods are based on the "3D model in small scales, such as houses, high-rise buildings, and urban blocks. While the researcher for calculating solar radiation in middle-scale and macro-scale need to integrate methodology. In this case, research focuses on this Scale to find a methodology and their correlation.

3. Methodology

Architects and urban planners often do not have enough knowledge and time to evaluate solar energy potential during the design process. Therefore, having a technical background and determining the appropriate time for analysis can help them achieve maximum solar potential and encourage them to study more efficient design solutions for integrating solar systems into building coatings(Lobaccaro et al., 2019). Realizing solar energy potential in the urban context requires determining the related criteria and parameters according to specific issues that should be considered(Amado & Poggi, 2014b).

This study was analytical and was based on sustainable urban development and documented principles derived by the authors in the two fields of urban design and urban morphology. The aim was to compare the ideal situation with the current situation and to achieve the average height codes in urban blocks for future planning by optimizing the current situation. In addition, to speed up the planning process, the study seeks a connection between two-dimensional solar radiation data and calculated and optimized three-dimensional data. Also, implementing a comprehensive approach to calculating solar radiation at different urban scales was another goal of this study. The process had been operationalized to help urban planners and designers link urban patterns and energy production factors. Then, a customized workflow was designed using the paradigm of parameters and essential indicators at a city scale. A workflow was developed using GIS, parametric modeling, and solar dynamic analysis at various scales based on Figure 1.

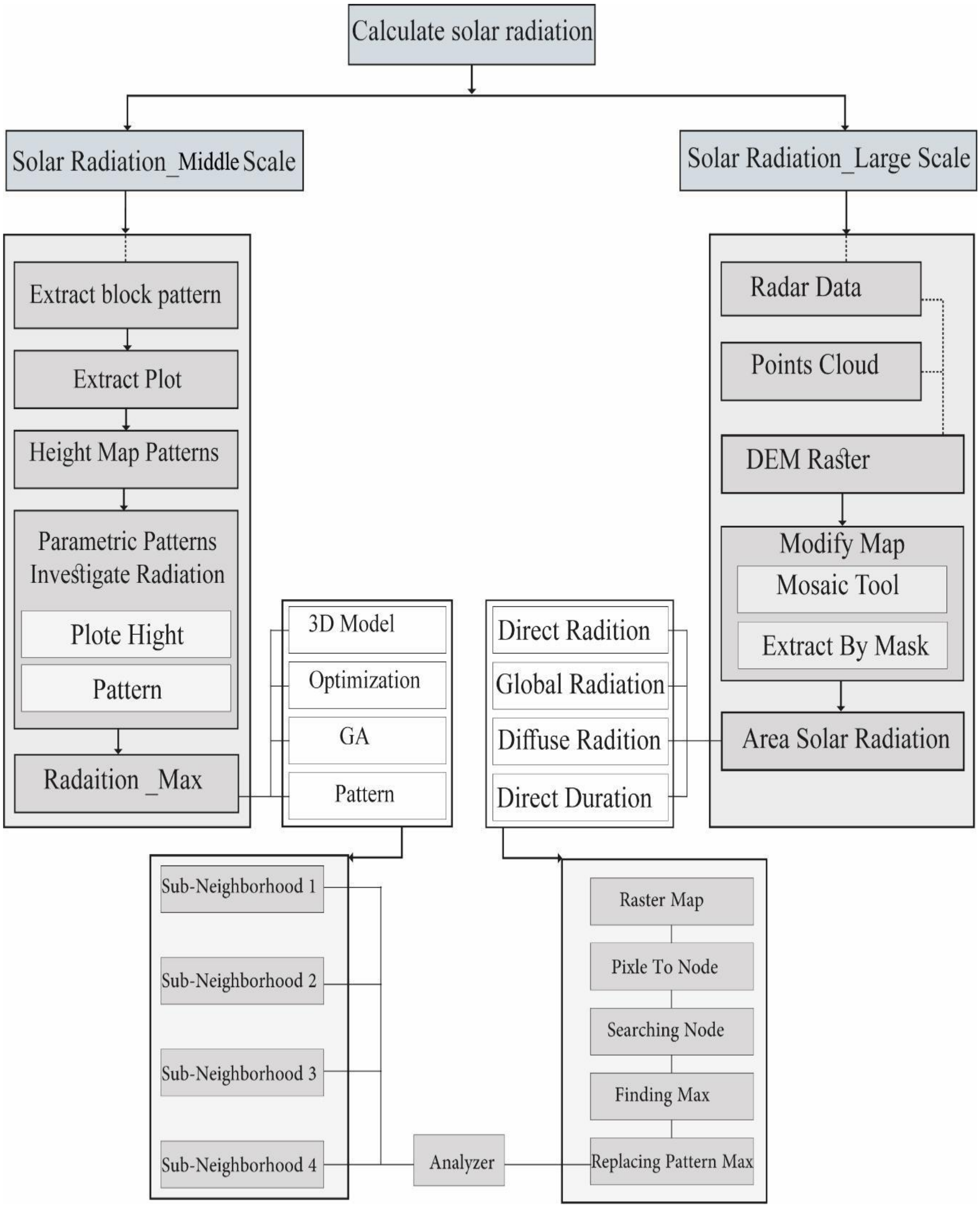

Figure 1 - General analysis of solar radiation at different levels of the city

Simulation tools were generally divided into three categories: building energy performance analysis tools, microclimate analysis tools, and finally, tools that address neighborhood shape and energy consumption(Wang, 2010). Moreover, solar radiation calculations can be divided into three categories based on the solar radiation model and the tool that classifies the three-dimensional form of the city. These include I) All-in-one model, which couples the modules used for solar radiation treatment with design interfaces or three-dimensional object representation in a single software; II) CAD plugin-based model, which receives plugins from other software capable of performing radiation analysis; and III) GIS-based models (Freitas et al., 2015). Accordingly, this study had divided research modeling into two different phases. In the first phase, designers and planners, who might not be able to provide accurate information about building construction details and performance details in the preliminary planning and design period of the site (Wang, 2010), study a layer of raster geographic information and makes it possible to examine displacement characteristics in the radiation model, such as slope, orientation, and latitude in large areas, on an urban planning scale (macro-scale) (Redweik et al., 2013).

The second stage, which was in the form of small-scale parametric data, marks the beginning of developing a research method with the ultimate goal of calculating solar energy at urban design and building architecture scales. The next step was to understand how to change urban planners' current design styles (mid-scale and micro-scale). To address the shortcomings of existing micro-scale techniques, the hybrid method of urban building energy modeling (UBEMs) has been proposed as a new simulation method, which uses bottom-up modeling with physics-based simulation techniques. Within UBEM, each building was presented as a thermal model based on the same principles of heat transfer that govern individual building energy models (BEM). Generation of UBEM requires the definition of countless input data for building geometry and a large set of non-geometric energy-related parameters (structures, systems, use patterns, loads, etc.). However, the model processes created for individual buildings can be applied directly to the urban Scale due to the larger model size and unavailability of data. They require the use of various abstraction and simplification methods. Several methods have been proposed for generating building geometry from GIS or LIDAR datasets and converting them to simple thermal models with reasonable simulation time (Cerezo Davila, 2017).

4. Case Study

The first step in improving the energy performance of buildings is to study and simulate their behavior. Many energy models and techniques have been developed for this purpose in recent years. However, these models are usually from the building designer's perspective, as they tend to consider buildings in terms of defined entities and ignore the importance of urban-scale phenomena. In particular, the effect of urban geometry on energy consumption is still controversial. One reason for this shortcoming is the problematic nature of modeling complex urban geometry(Ratti et al., 2005).

The study area was the Farhangian neighborhood, phase 1, located in region two of Kermanshah, Iran. This neighborhood is bordered by the Bargh neighborhood from the north, Sarcheshmeh neighborhood from the south, Dieselabad neighborhood from the east, and Taxirani from the west. Farhangian neighborhood, phase 1, is located in a strategic area of the city in terms of location in Figure 2. This neighborhood has excellent potential for vertical expansion and development due to its proximity to the main urban square and is located in the central metropolitan area. Such a development is access to more municipal services and high land prices in these areas. Therefore, creating indicators and criteria for sunlight access in this area is particularly important.

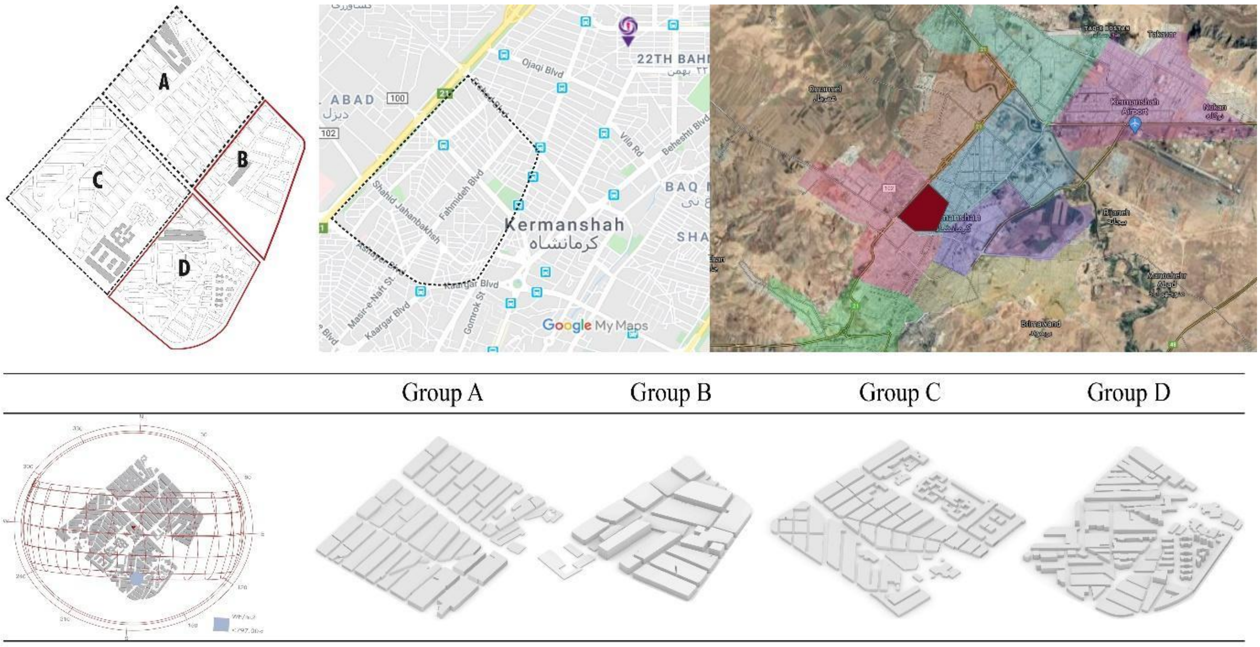

Figure 2- Location of region 2 in Kermanshah and the relative location of the research site

Region 2 of Kermanshah is one of the newly built regions with high economic potential with old patterns due to special blocks. The possibility of vertical development in the region was also increased due to its good access and convenient distance from the city center. In addition, various patterns of blocks can be seen in the area. Therefore, Farhangian neighborhood of Kermanshah was selected as a suitable site for initial analysis. Next, a general analysis of the site was carried out, and 2.5-dimensional radar data and two-dimensional data at the urban block level were reviewed to select index block patterns for final analysis.

5. Results and Discussion

Energy calculations at different stages of design require a comprehensive approach. Though Rodríguez-vlvarez adapted thermal and lighting calculations for use at the urban Scale (Rodríguez-Álvarez, 2016). these calculations do not have optimal performance for different scales. On the other hand, various methods and software are used to study energy variables in the analysis and study of urban morphology. Depending on the Scale and complexity of the study, the study of urban morphology was faced with certain complexities. Hence, this analysis can be reduced at large-scale data and up to the building scale. Entering different energy categories further exacerbates this complexity. Therefore, researchers generally studied energy in two general areas. The first area, which includes technology and urban economic models, was investigated via a top-down approach. In contrast, the second area, which was divided into engineering and statistics, involves using a bottom-up method.

Urban building energy modeling is done through main approaches, i.e., "top-down" and "bottom-up"; The top-down approach involves using known energy consumption for a specific area and period (usually annual) and dividing it into sections attributed to particular groups of buildings. The bottom-up approach takes a reverse path and creates models at the Scale of single buildings with the same energy consumption. Then, the results were summarized for all buildings in the complex. While both approaches aim to describe energy consumption, the top-down models were limited because they were trained using historical data on consumption levels, construction conditions, economic indicators, etc. The ability to predict relies very small on changes in the status quo and, therefore, cannot model the consequences of technological advances, changes in construction practices, etc. The bottom-up approach did not have such limitations. Another advantage was that energy consumption could be divided into final uses right from the beginning, and the results could have a high spatial resolution(Cerezo Davila, 2017).

Therefore, analyzing data in the field of energy and the management, calculation, and amount of this energy needs to be studied in various areas of urban modeling. However, studying these areas at different scales is impossible with a single tool to optimize early urban models. The duration of large-scale radiation energy analysis may not be cost-effective in terms of time and cost. Therefore, different tools should be used depending on the process and the area under study. This study provides different models at each level. It analyzes each in terms of management and design studies that can effectively carry out solar radiation analysis within an urban block.

6. Solar radiation: modeling city planning

Various methods have been developed for modeling solar radiation that differs mainly in their scattered radiation estimation. Some solar potential estimation methods have been developed In recent years that consider topography from LiDAR data(Bizjak et al., 2015). GIS-based models with the ability to display real-world space for visualization and simulation purposes have been the most powerful. In terms of GIS presentation, there are two ways to obtain a digital surface model (DSM) in an urban environment: i) achieving a set of three-dimensional points allowing the geometric reconstruction of the elements under study, and II) using procedural or parametric modeling (Machete et al., 2018). The most common is three-dimensional models derived from LiDAR through automated algorithms or manually devised with a simple CAD method and building footprints. The input data are used for defining 2.5d raster layers (building heights, facets, slopes, etc.), which, along with other tool settings, form input data for GIS-based solar analysis(Pili et al., 2018). Various methods should be used to assess the solar potential of urban areas. Of these, it has been shown that geographic information systems (GIS) help estimates regional renewable energy potential and practical support for urban-scale energy planning decision-making (Groppi et al., 2018).

The first step in energy analysis was to prepare the maps needed for measurement. There were two ways to receive raster data (DEM). First, radar data taken from sources like the United States Geological Survey can be used. In this case, the map was based on 30*30 big black and white mosaic parcels. The Scale of these maps was so large that the entire neighborhood being investigated was summarized in a few parcels, which was a fundamental problem in analyzing solar radiation data. Solar radiation analysis performs calculations according to these parcels, and each parcel represents a certain amount of radiation, so fewer parcels means less radiation information.

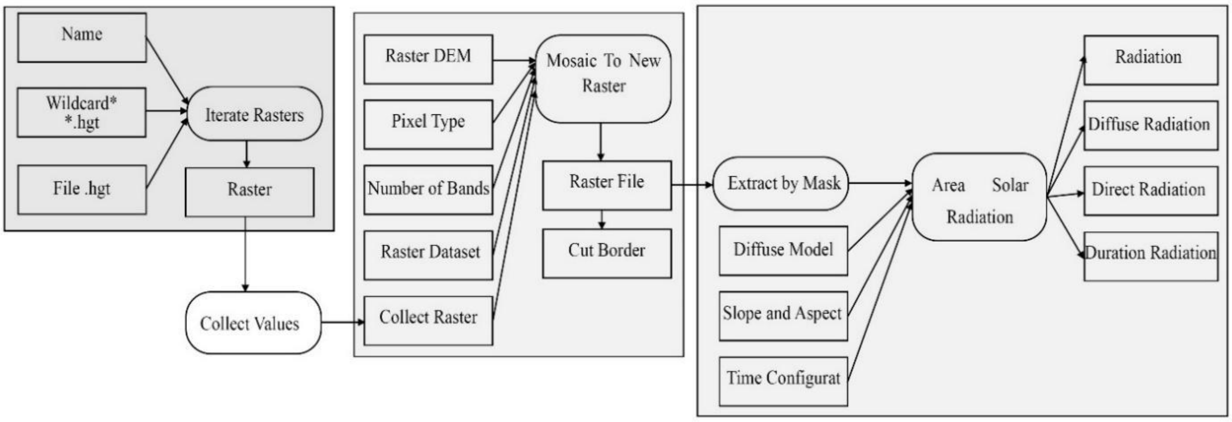

Figure 3. Algorithm of the generated tool for calculating solar radiation using radar data

The second mode for calculating radiation was using data generated by point cloud in Google Earth software. To this end, we need to create a point cloud on the desired location based on map data in Google Earth. Then, the cloud point was entered into www.gpsvisualizer.com to add height data to these points (Visualizer, 2018). The website uses the global DEM data to add a third column to the set of issues that show the height code of our intended points. Then, this TEXT data was entered into the GIS environment and converted into points, which were then converted into a DEM file using Point to Raster tool. The advantage of this method was the creation of a raster map with pixel dimensions of 5*5 meters. This was much smaller than the pixels in the previous process, which provides the user with larger and more detailed maps. This model was selected for the accuracy of its operation. Figure 3 summarizes the steps of structural investigations in solar analysis. After the above steps, the data was entered into the Area solar Radiation plugin in the Arcmap tool for research. The output can be seen in Figures 4 and 7.

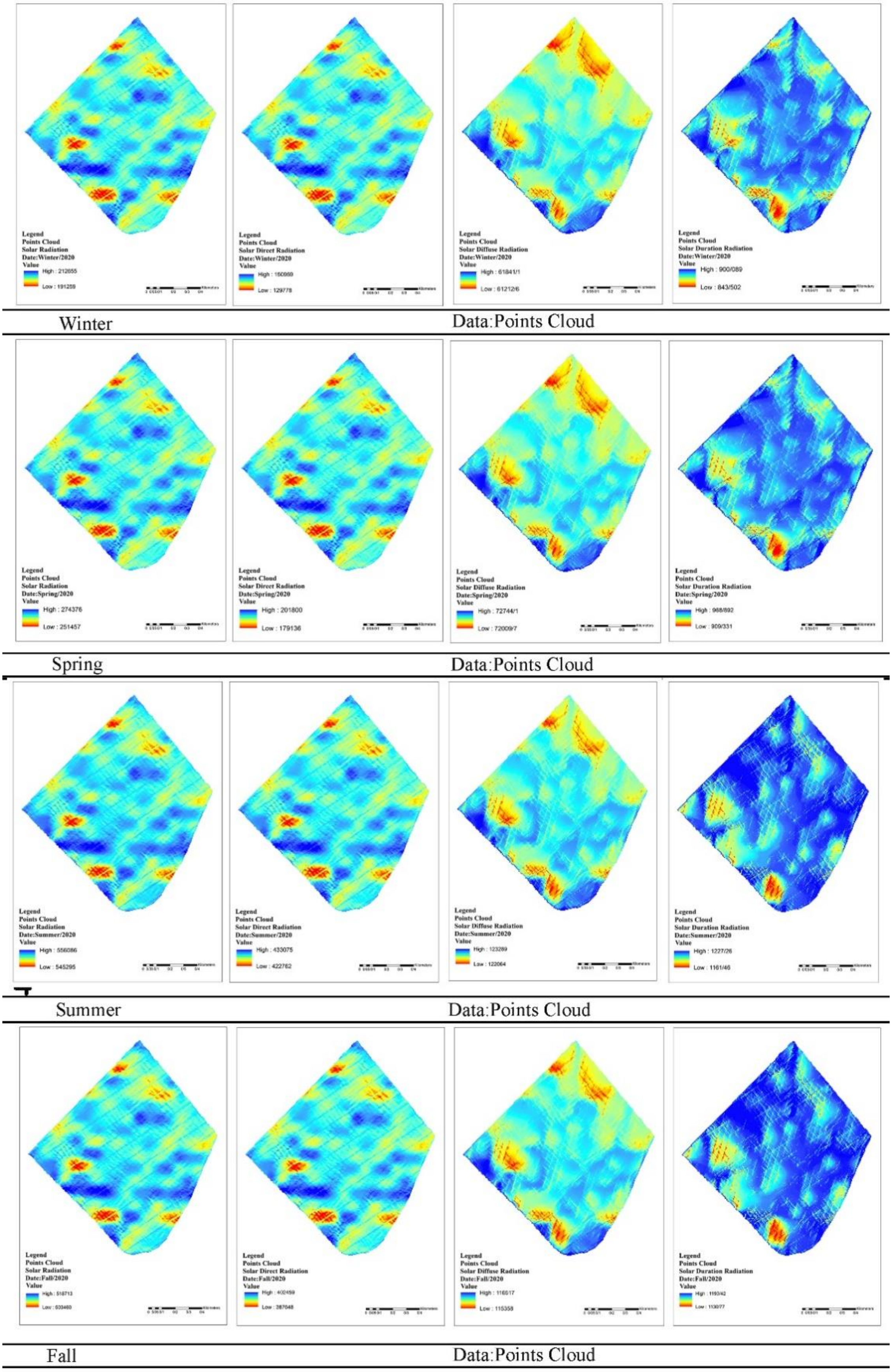

Figure 4. Solar radiation chart in different seasons of the year

The diagrams in Figure 4 above show the amount of solar radiation in different seasons of the year based on four variables, each in a particular range based on the radiation amount. Two critical variables in this area, which were significant for this study, were radiation duration and direct radiation.

Table 2. The amount of total, direct, and diffused radiation of the sun in different seasons of the year

	winter		spring		summer		Fall	
	Max	Min	Max	Min	Max	Min	Max	Min
Solar Radiation	220868	184489	282972	244114	558118	541127	522860	498004
Solar Direct Radiation	159549	123065	210836	171858	435835	418653	407296	382258
Solar Diffuse Radiation	61849	61040	72753	71809	123302	121736	116530	115047
Solar Duration Radiation	900	8431	968	904	1227	1154	1193	1122

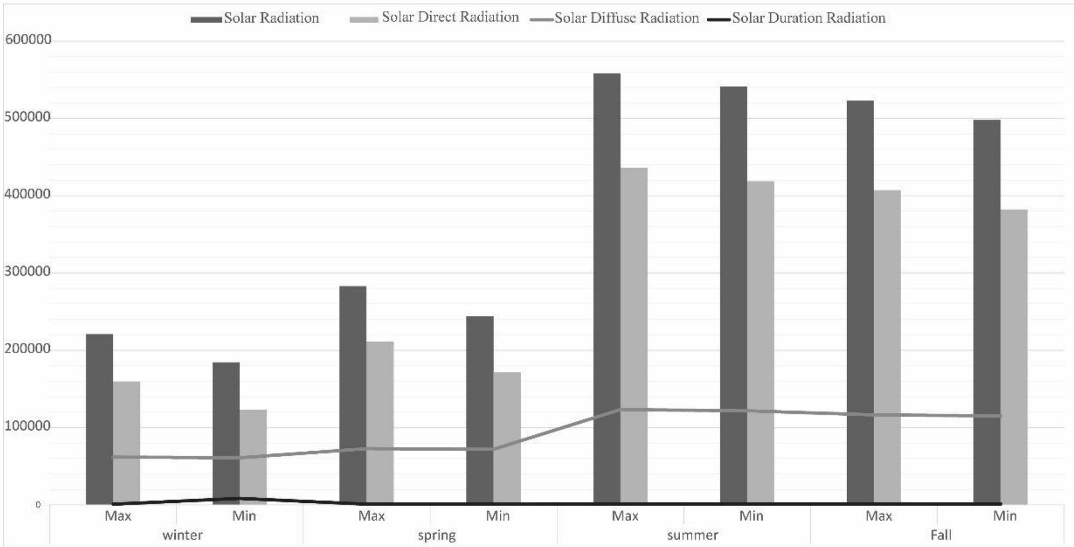

Figure 5 - Bar chart comparing different amounts of solar radiation in different seasons

Comparing different seasons in Table 2 and Figure 5 in the radar and cloud point data shows clearly that the ratio of direct radiation to total radiation in summer and autumn was higher than in the rest of the year. Likewise, natural radiation had a larger share of total radiation than other computational radiations. This was why, in many studies, these two outputs were considered equivalent.

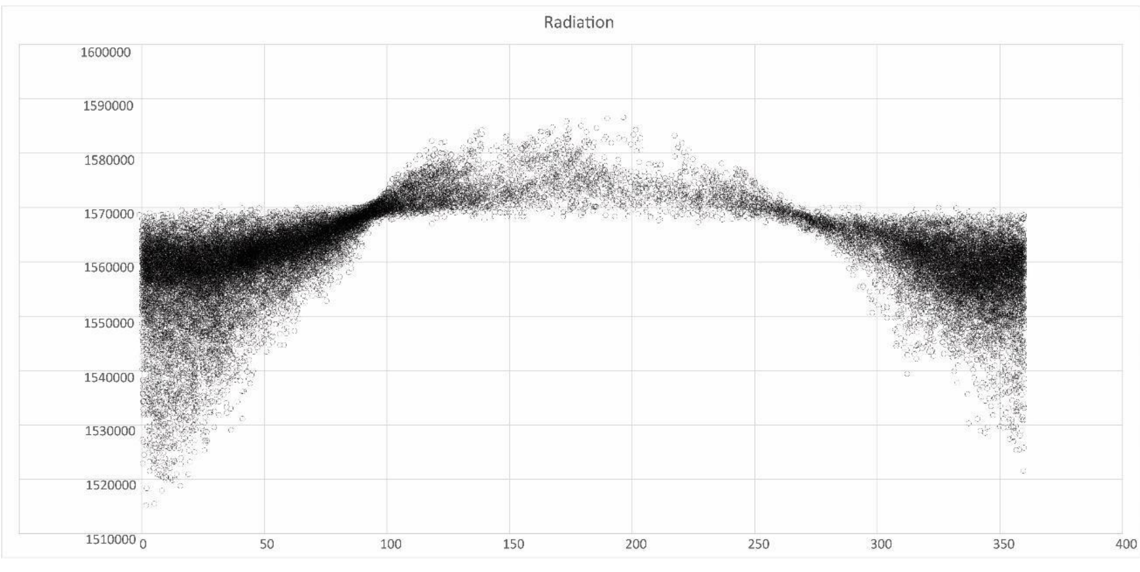

Figure 6. The amount of solar radiation relative to the earth orientation

Inspection of the data in Figure 6 shows that the distribution of radiation changes at different times of the year was expected, and statistical tests can examine the changes in the data. On the other hand, it confirms that point cloud data provides higher accuracy and more information and can present on-site radiation information for different points with different values. This can give planners and city managers more decision-making power when planning land use. Therefore, there was a clear need for higher quality satellite data for further research.

Table 3. Correlation among amounts of radiation in different seasons

	Winter_Radiation	Summer_Radation	Spring_Radiation	Fall_radiation
Winter_Radiation	1			
Summer_Radation	0/997508686	1		
Spring_Radiation	0/996560543	0/988235843	1	
Fall_radiation	1	0/997508686	0/996560543	1

The relationship between radiation variables in Figure 5 and Table 3 shows a direct connection between the rate of change at different times of a season in a single region. The points that receive more radiation in a season during a year follow the same pattern in other seasons, and the same way can be used in planning. The study of the annual radiation variable using radar data in Figure 6 shows a significant amount of radiation in Farhangian, phase 1 in Kermanshah. What was essential was the use of satellite data for planning on energy and urban scales. According to the 2.5-dimensional DEM data, the minimum and maximum amounts of radiation energy for the Earth's surface area are 1.4 and 1.6 million kWh, respectively. Therefore, a significant difference can be made in the received radiation by choosing optimal locations.

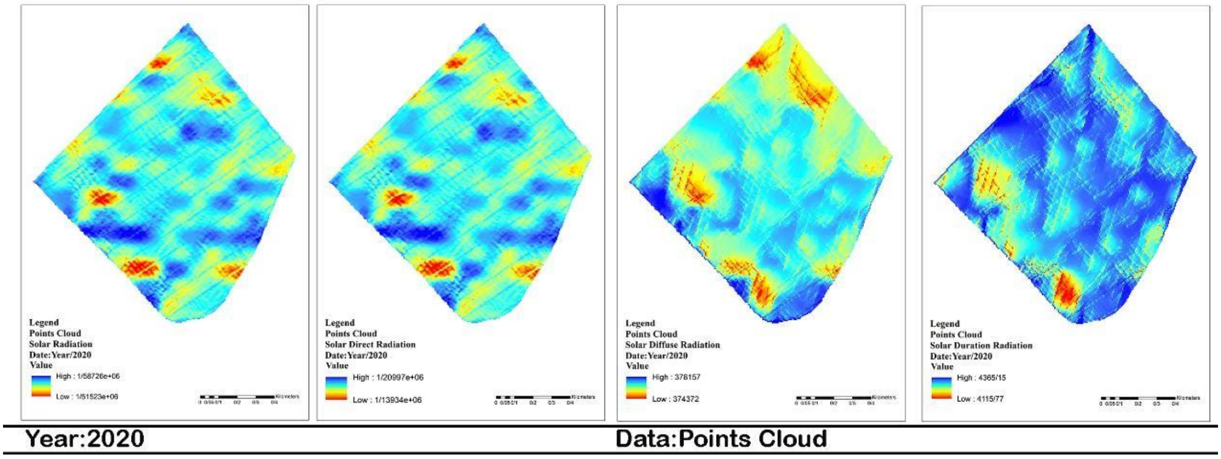

Figure 7 - Annual solar radiation in Farhangian, Phase 1 region of Kermanshah using the point cloud technique

Annual data on solar radiation in different modes confirmed the importance of solar radiation hours during a year. This data was essential because no technology can use all the solar radiation energy, both in the passive and active areas. Thus, the duration of time when solar energy was available was more important than its amount. Here, the sunshine time was maximum in most parts of the site, as shown in dark blue in Figure 7. The maximum annual number of hours is 4365, suitable for using radiant energy in the study site.

Table 4. The amount of annual radiation in the point cloud method

Year2020					
	Max	Min		Max	Min
Solar Radiation	1610850	1490940	Solar Diffuse Radiation	378202	373351
Solar Direct Radiation	1235810	1115300	Solar Duration Radiation	4365	4091

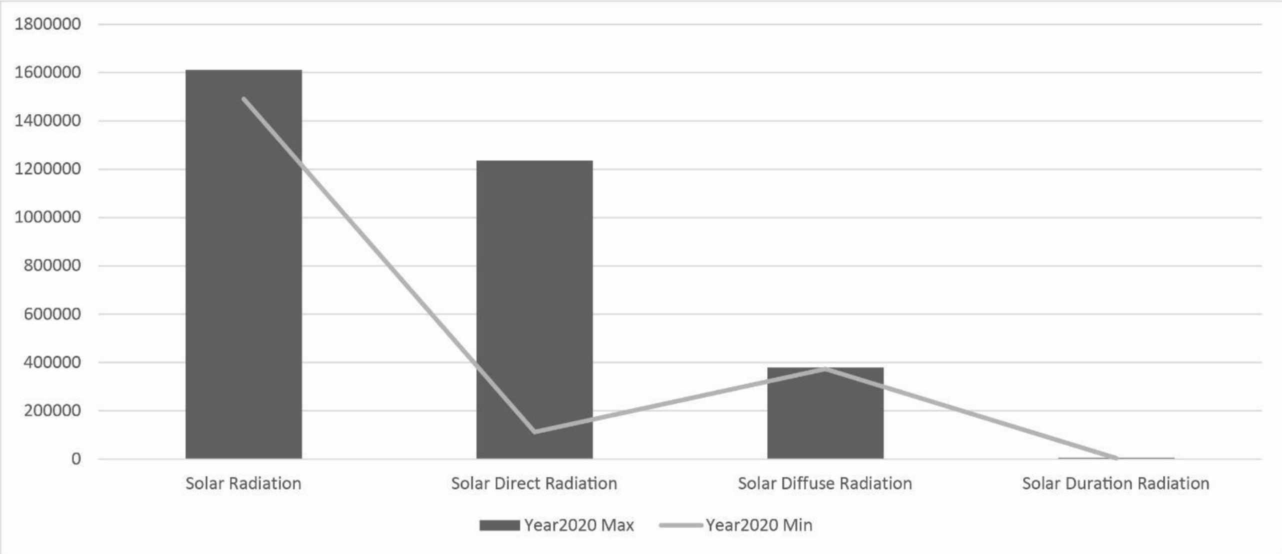

Figure 8- Comparison of the amount of annual radiation in point cloud method

In the study of the amount of annual radiation in the point cloud method, direct radiation was maximum, comprising more than 80% of the total radiation energy. In other words, comparing the radiation time and the amount of direct radiation shows that cloudy days in this region were low, which can further be corroborated by examining climate data.

Table 5. Comparison of annual radiation in the point cloud and radar mode

	Radar		Point Cloud	
	Max	Min	Max	Min
Solar Radiation	1610850	1490940	1587260	1515230
Solar Direct Radiation	12358100	1115300	1209970	1139340
Solar Diffuse Radiation	378202	373351	378202	373351
Solar Duration Radiation	4365	4091	4365	4091

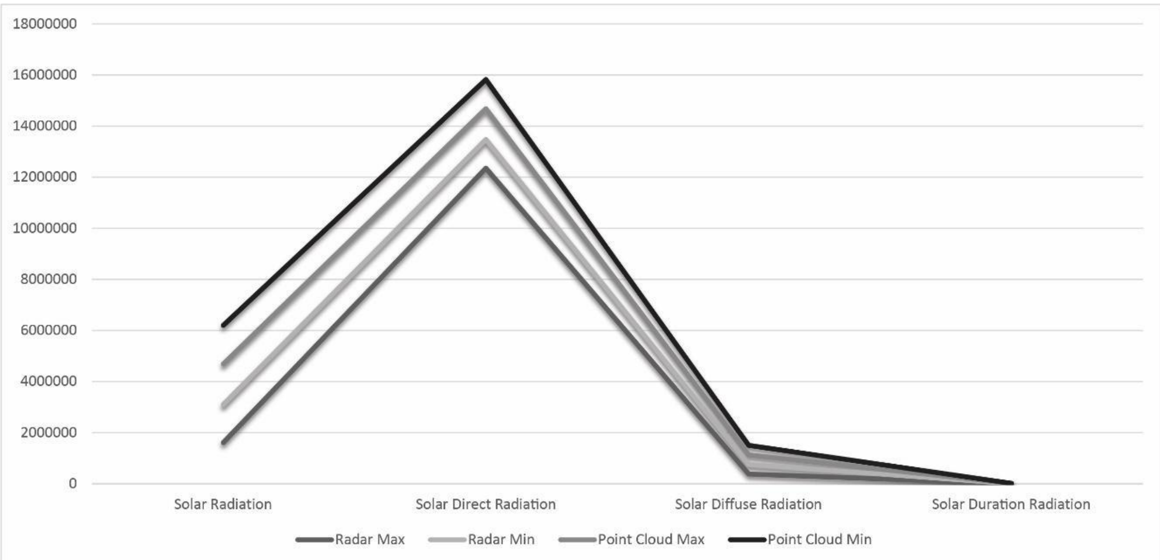

Figure 9 - Comparison of annual radiation in the point cloud and radar mode

Examining the radiation diagrams in Figure 9 and Table 5 shows two cases in which the changes in the two graphs follow the same pattern and their differences are at an acceptable level. Similarly, in places where the amount of point clouds is at its maximum, the radar mode was also at maximum, and in cases where the amount of solar radiation energy was at a minimum, the same is valid for radar data.

7. Solar radiation: modeling urban design

To facilitate simulation and performance evaluation, an integrated workflow using the Grasshopper parametric modeling plugin for Rhinoceros3D software(Scott, 2010) and the Ladybug plugin (Roudsari, 2017) in Grasshopper was created for both solar radiation and building energy. This custom workflow integrates the functions of three-dimensional parametric modeling of buildings, performance simulation, calculation of geometric variables and performance indicators, data processing, and visualization of results in an integrated manner. The meteorological data of Kermanshah, Iran, had been used in the form of an EPW file(EnergyPlus_Development_Team, 2020) as input for solar radiation and building energy simulation, which includes statistical data representing some important meteorological parameters for a particular place, such as global and hourly horizontal radiation, dry-bulb temperature (DBT), relative humidity, wind speed, etc.

The study of urban blocks in the intermediate level was done to identify urban blocks and the effects of different types and heights of the blocks of a neighborhood in absorbing the energy radiation of the surfaces. But as the figure below shows, examining all areas of a neighborhood comprising hundreds of blocks and thousands of plots with different height codes was a challenging and time-consuming task, which precludes further investigations by the user. Therefore, this study examined the average height of urban blocks in the sub-neighborhood scale. Thus, the Farhangian neighborhood, phase 1 of Kermanshah, was divided into four groups separated by the main routes. This ensures that the impact of the blocks on both sides of the street was minimized and did not interfere with the overall analysis.

To study and analyze solar radiation on a local scale, three-dimensional data in the form of mesh surfaces were required in addition to two-dimensional maps. This simulation did not just serve the purpose of a general data analysis but aimed to optimize the height of urban blocks and their research. Therefore, among the solar radiation analysis software, the Grasshopper plugin in Rhino software was used in this study to convert GIS maps to parametric 3D maps. The following algorithm was used in the Grasshopper environment to create these three-dimensional patterns.

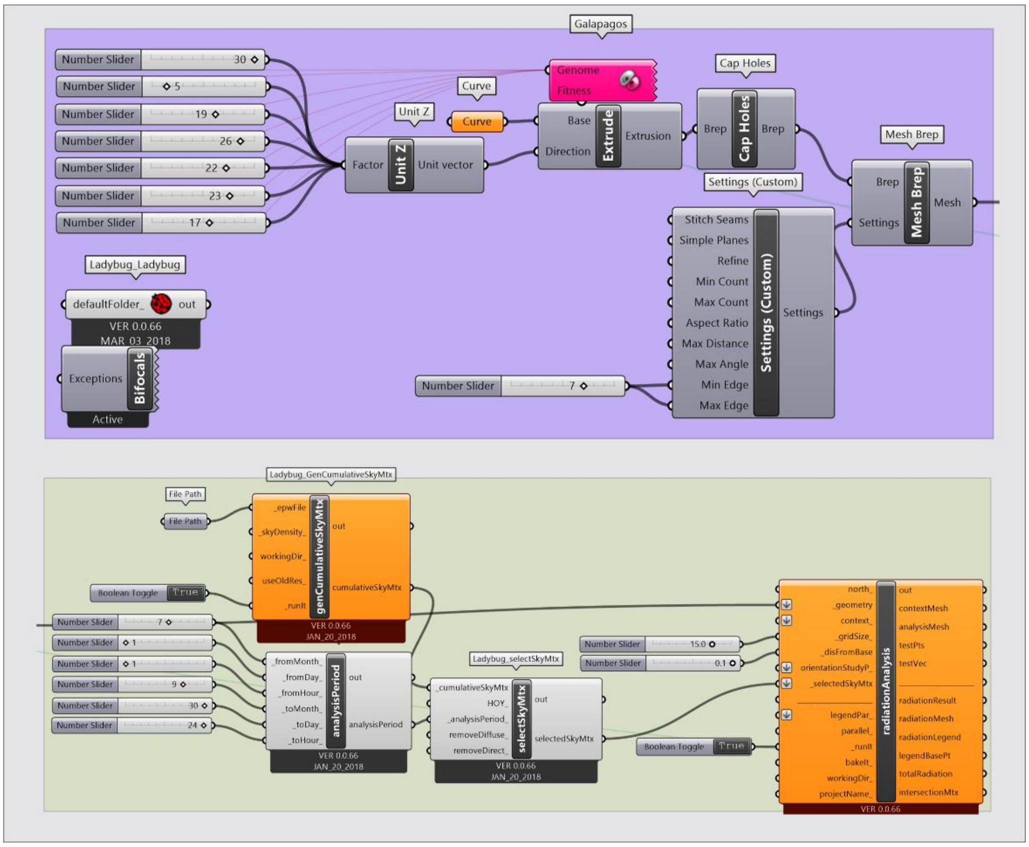

Figure 10 - The final algorithm for solar radiation on a neighborhood and urban block scale

The final algorithm shown in Figure 10 consists of four parts prepared for optimization on microscale dimensions. This algorithm could optimize a set of urban blocks using changes in the height dimensions. In the first part of the algorithm, there were data recorders for storing data on changes in height and the amount of solar energy absorption. The second part placed the variables required for creating three-dimensional volume. The third part includes the variables needed to measure solar radiation. Finally, the tools needed to display the amount of radiation and the height dimension were placed on each block, which was an innovative measure taken by the researcher, with the possibility to delete or add other parts to it. The following sections examined radiation at the sub-neighborhood micro scale.

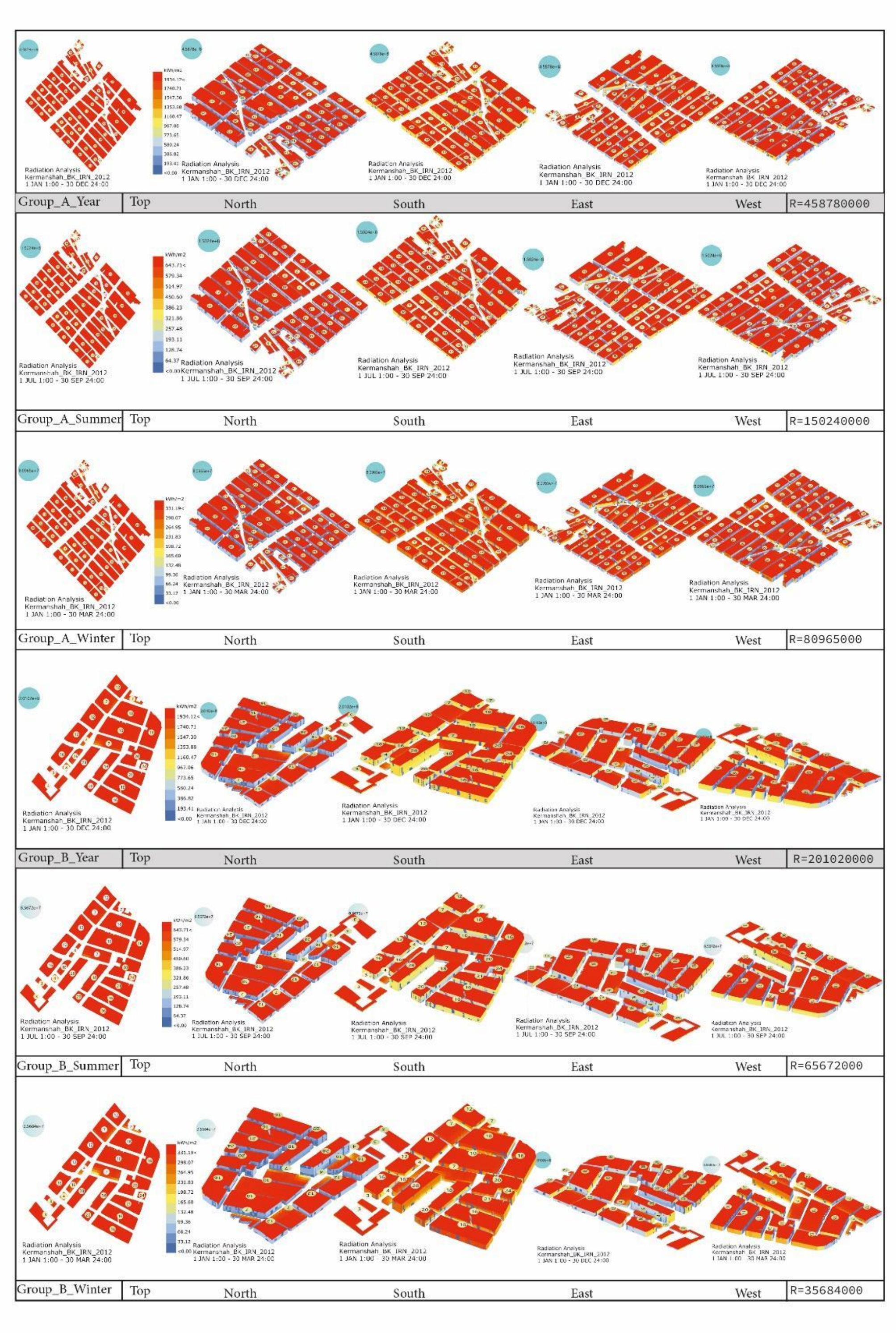

Figure 11 Calculation of solar radiation at sub-neighborhood scale for group A_B in winter and summer

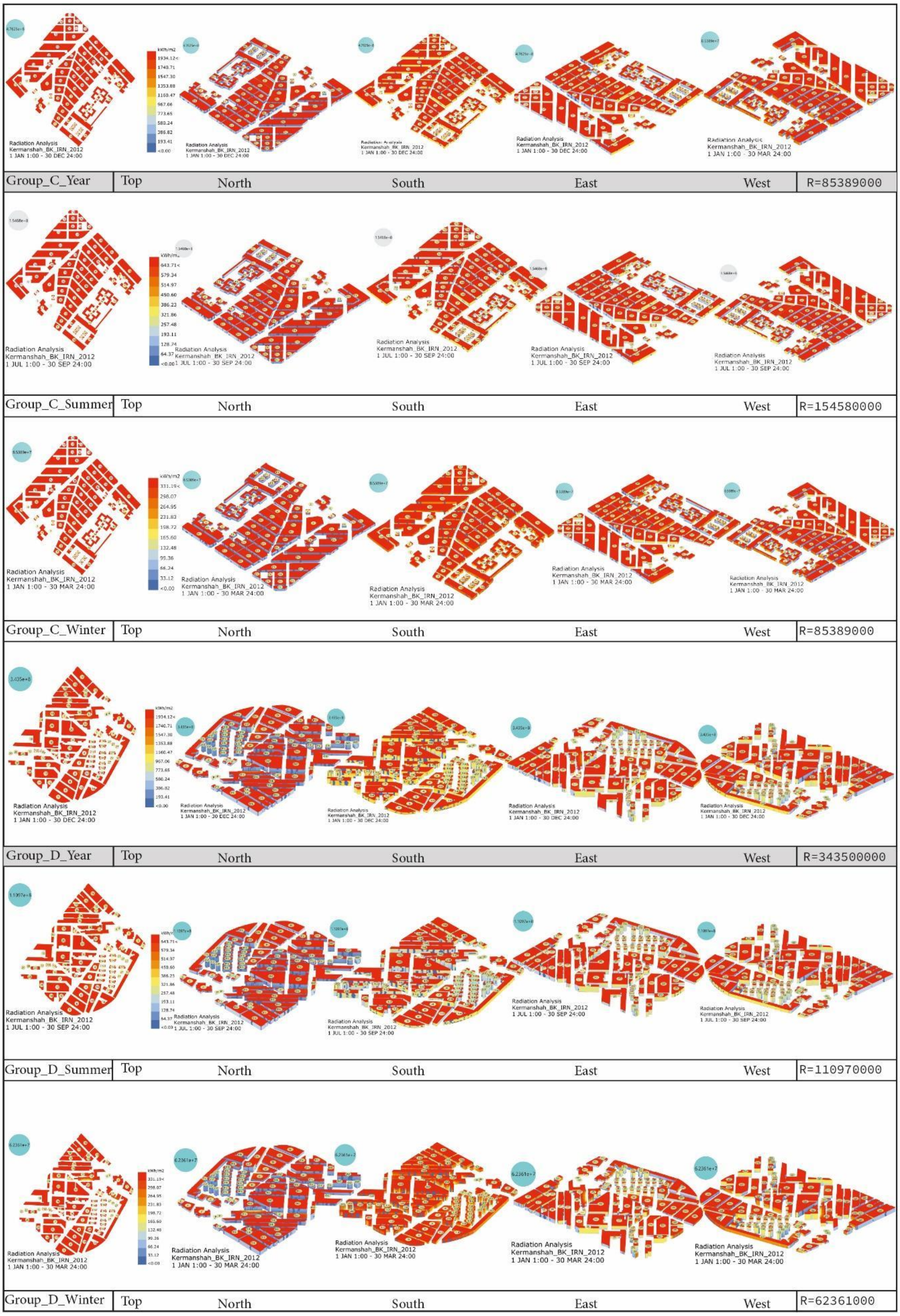

Figure 12- Calculation of solar radiation at sub-neighborhood scale for C_D group in winter and summer

Based on the evaluation of the patterns in different seasons in Figures 11 and 12, the facade surface data support our previous hypothesis that the energy absorption was constant compared to other surfaces in different directions. This means that energy absorption was consistently higher in the southward and westward surfaces of the region than in the northward and eastward ones. The amount of energy absorption in the height variable of 1 to 30 square meters, which was the range of height changes in our four groups, shows that climate change was almost the same for all elevated surfaces. The study of the higher height range was not performed due to the complexity and nature of the research that sought to optimize the status quo. On the other hand, ten residential floors equal to 30 meters were the allowed height limit in local regulations.

Table 6. Investigation of the amount of radiation in the four sub-neighborhoods of Farhangian, phase 1 by year and season (summer and winter)

	Year	Summer	Winter
Radiation_GroupA	458780000	150240000	80965000
Radiation_GroupB	201020000	65672000	35684000
Radiation_GroupC	476250000	154680000	85389000
Radiation_GroupD	343500000	110970000	62361000

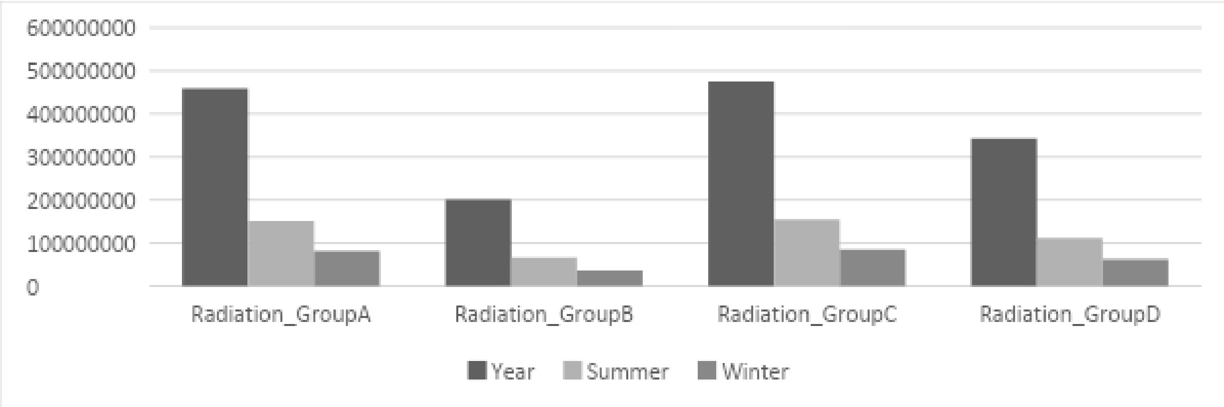

Figure 13- Diagram of changes in the amount of radiation in the four sub-neighborhoods of Farhangian, phase 1 by year and season (summer and winter)

Examination of the amount of radiation in winter and summer in Figure 13 and Table 6 shows that solar radiation in summer was about 50% higher than solar radiation in winter. This ratio has always been constant in two-dimensional and three-dimensional studies. Changes can be seen in other seasons due to the angle of incidence, and other atmospheric factors such as clouds, which prevent radiation from reaching the ground.

8. Optimization algorithm in an urban block

The radiation and its nature in urban space were associated with many complexities due to many related variables and factors in the city. Assuming that the research time was constant, variables such as the height, length, and width of the block, the shape of the league, the number of lots and their orientation and Scale, etc., were just a few quantitative parameters affecting solar radiation in an urban block. Calculating solar radiation becomes more extended when the number of blocks increases and optimization becomes more complicated. Therefore, each of these algorithms had complex calculations and a specific type of method for obtaining the answer. For example, cold metal, genetic, ant colony, etc., are only part of the answer process. Given the continuous amount of radiation in a city, this study uses a genetic algorithm. This algorithm continuously examined different parts of the site. It optimized the amount of radiation based on the maximum amount of radiation with height changes in the range of 1 to 30 meters, taking into account changes in height dimension and other variables. This range and restriction in height dimension was the limited optimization time. Indeed, the higher the levels of these variables, the longer the optimization time.

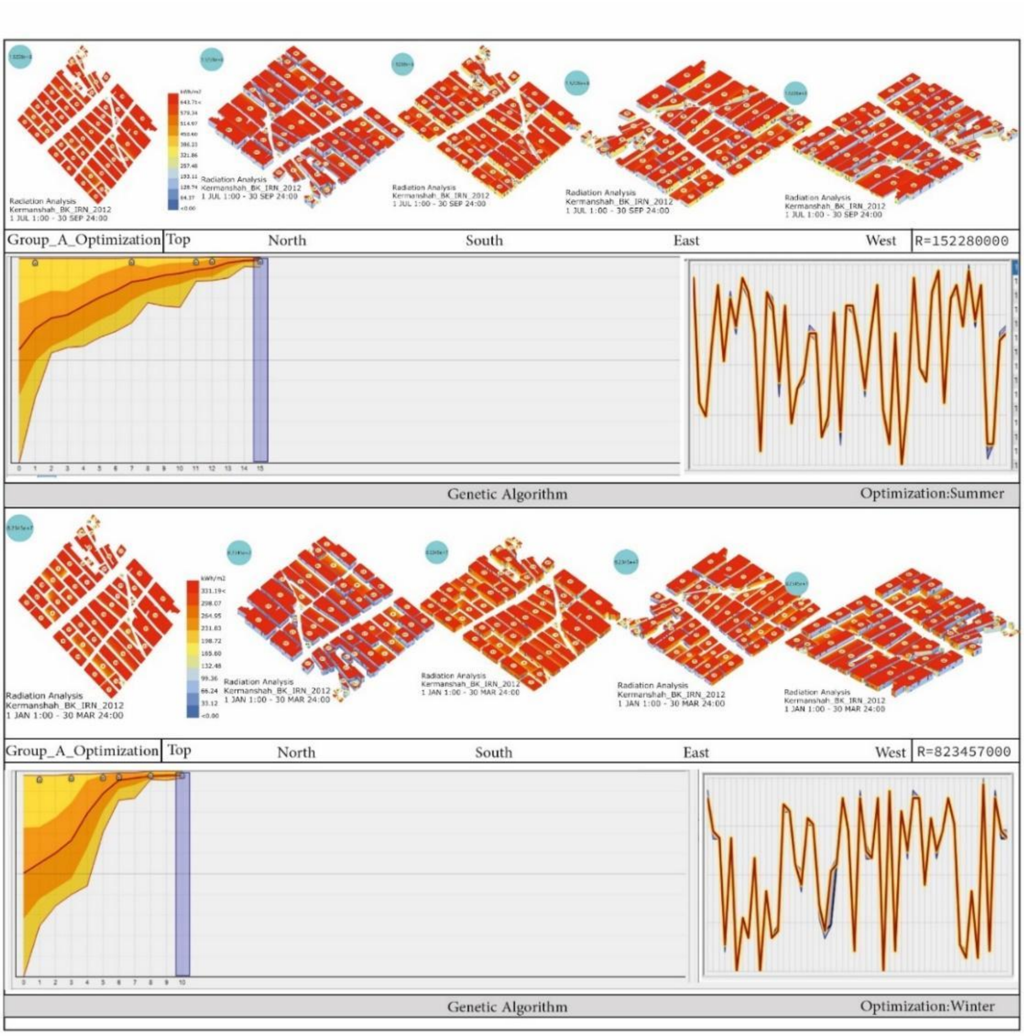

Figure 14 - Optimization of urban block variables in winter and summer in group A.

The optimization data in Figure 14 show that the optimizer modifies its data over time and places a mark on the image by achieving new records. Figure 15 shows the optimized data, which was the final result of examining the height variable.

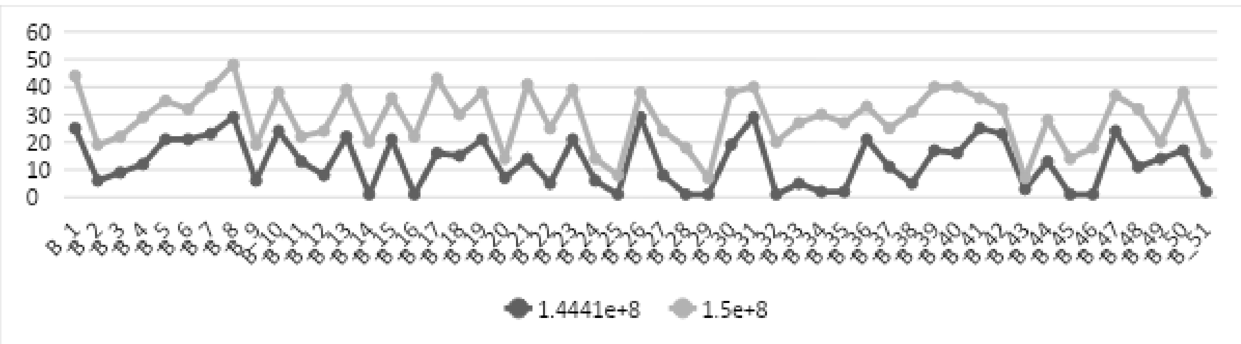

Figure 15- Height changes in the existing and optimized states

In Figure 15, the height dimension changes can be seen for both existing and optimized states. The height dimension changes had been increasing but did not reach the maximum level, i.e., 30 meters, remaining at the average range of 15 meters. According to the results, the difference between summer and winter shows different optimizations, as seen in the figure below. Height changes, in this case, needs further investigation, and no definitive conclusion can be drawn.

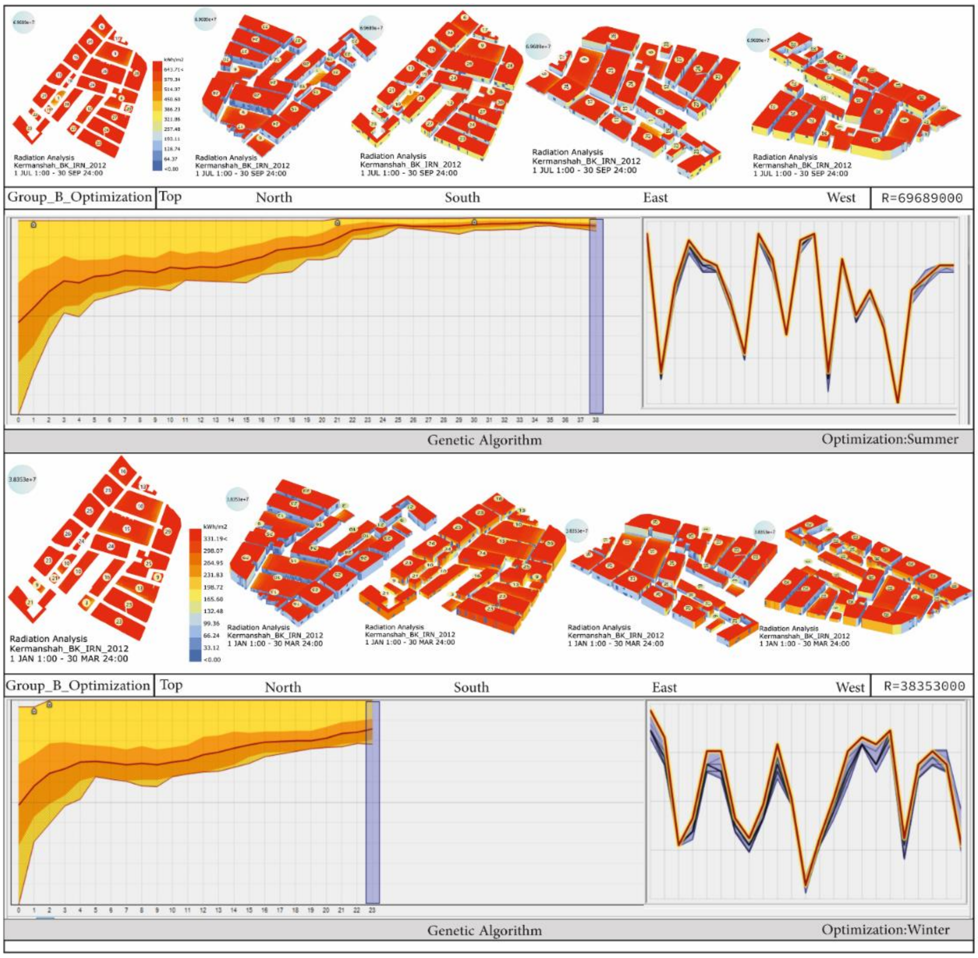

Figure 16- Optimization of urban block variables in winter and summer in group B.

Examining more patterns in Figure 16 in terms of optimization in the subgroups is further revealing. The average height and the amount of optimization show that the data gradually move towards a more optimal pattern with changes in height variables. However, these patterns in all dimensions of change never moved to maximum height so that the average size is usually 50% of the general state. A careful look at the optimal state marked with gray showed that the amount of radiation absorbed in the urban context has increased by 5 to 10%.

Table 7. Comparison of optimal and existing states based on output variables from genetic algorithm analysis

	Radiation	Avregie_High	Count_Block	Max_High	MinHigh
Group A_summer	1.4441e+8	12.94	50	29	1
Optimiz A_summer	1.5e+8	15.88	50	28	4
Group A_winter	7.6861e+7	13.22	50	29	1
Optimiz A_winter	8.23e+7	16.22	50	29	1
Group B_summer	6.5861e+7	13.69	23	28	3
Optimiz B_summer	6.9702e+7	19.04	23	28	2
Group B_winter	3.3903e+7	13.69	23	28	3
OptimizB_winter	3.8353e+7	15.78	23	26	3
Group C_summer	1.5468e+8	12.63	63	18	7

Table 7 Continued

Optimiz C_summer	1.6e+8	15.93	63	27	1
Group C_winter	8.5389e+7	12.63	63	18	7
OptimizC_winter	8.9074e+7	16.31	63	29	1
Group D_summer	1.1077e+8	14.32	77	27	4
Optimiz D_summer	1.15e+8	16.53	77	28	1
Group D_winter	6.2361e+7	14.32	77	27	4
OptimizD_winter	6.5319e+7	16.29	77	30	1

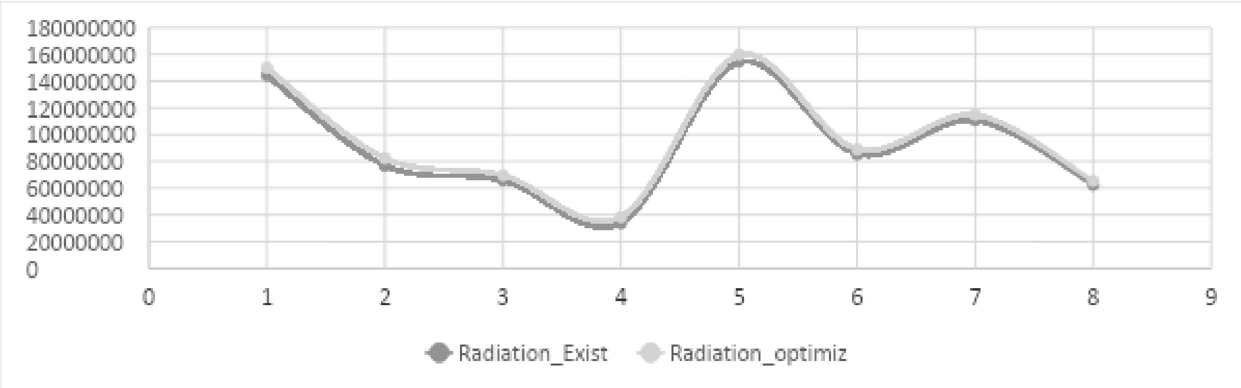

Figure 17 - Comparison of optimal and existing states based on output variables from genetic algorithm analysis

The optimized sample in Table 7 and Figure 17 shows that the height optimization rate increased radiation energy absorption by only 3 to 5%. However, it should be noted that in this case, factors such as the amount of light absorption for indoor environments, reduced power consumption, and other unusual uses can have a significant effect on reducing energy consumption in large structures. On the other hand, even a one percent increase was energy absorption efficiency can dramatically reduce energy consumption because this one percent gives us usable energy. Therefore, it can be expected that only adjusting the height dimension in sub-neighborhoods relative to each other can significantly change the amount of solar energy absorption by 3 to 5 percent.

Height investigations, in this case, include hundreds of different data subdivided due to the nature of the research. However, studying these sub-neighborhoods requires a comprehensive investigation system that categorizes and analyzes the data. On the other hand, in this case, artificial intelligence was responsible for height optimization, and as Galapagos software used for optimization had fixed command codes to keep the optimization process and repeated this process up to 50 steps. It changed the height about 25 to 100 times for each neighborhood, depending on user settings, and re-apply radiation calculations for each step. If about 500 new record analyses did not obtain a new record of maximum radiation, the optimization was stopped. Therefore, the optimization process here was incomplete due to time constraints. However, previous researchers had pointed to this incomplete code in the optimization process and suggested a discrete approach obtained from the ant colony method for optimization processes where time was an essential element.

Figure 18 shows the height investigation in the optimized mode for two seasons of the year. These data are close to each other. We had set the time according to the season at this stage to limit time concerning speed so that the optimization speed can be increased in a shorter duration. It was emphasized that this height code was not the final optimal state, and the optimization process took more time.

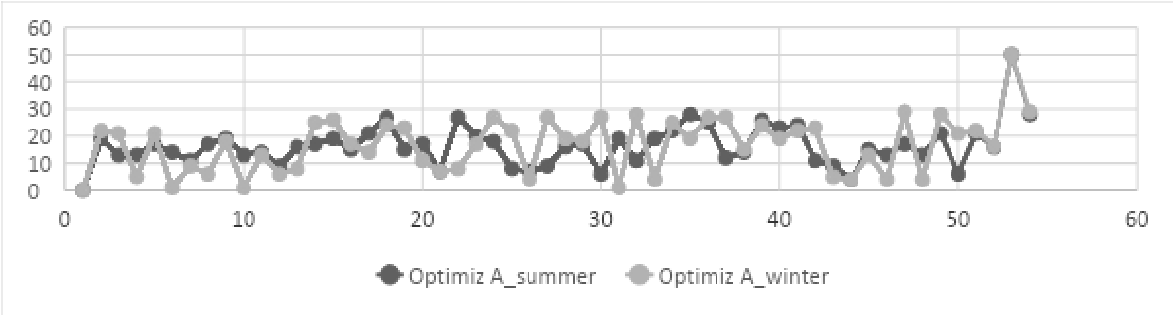

Figure 18 - Comparison of optimal winter and summer conditions related to height changes of group A from genetic algorithm analyses

Our preliminary studies in Figure 19 demonstrated the influence of radiation absorption from the Earth morphology on the macro-level data. This study shows that radiation absorption in different seasons with the proper location in an urban block can be expected to increase up to 200%, which was beyond the scope of this study. Finally, the final analysis of this study is to match the macro-level data and the average height of existing and optimized blocks. In the process of optimization based on genetic algorithm, it was expected that in optimization based on genetic algorithm, height changes occur based on maximum solar radiation in correspondence to changes of solar radiation in the macro-level data, i.e., satellite data. Data analyzed via adaptation of the optimized data and the height change data (Figure 19) shows that these data did not change according to the satellite algorithm and the morphological structure of the Earth. In other words, these changes were not significant, indicating a need for further research tailored to adaptive algorithms.

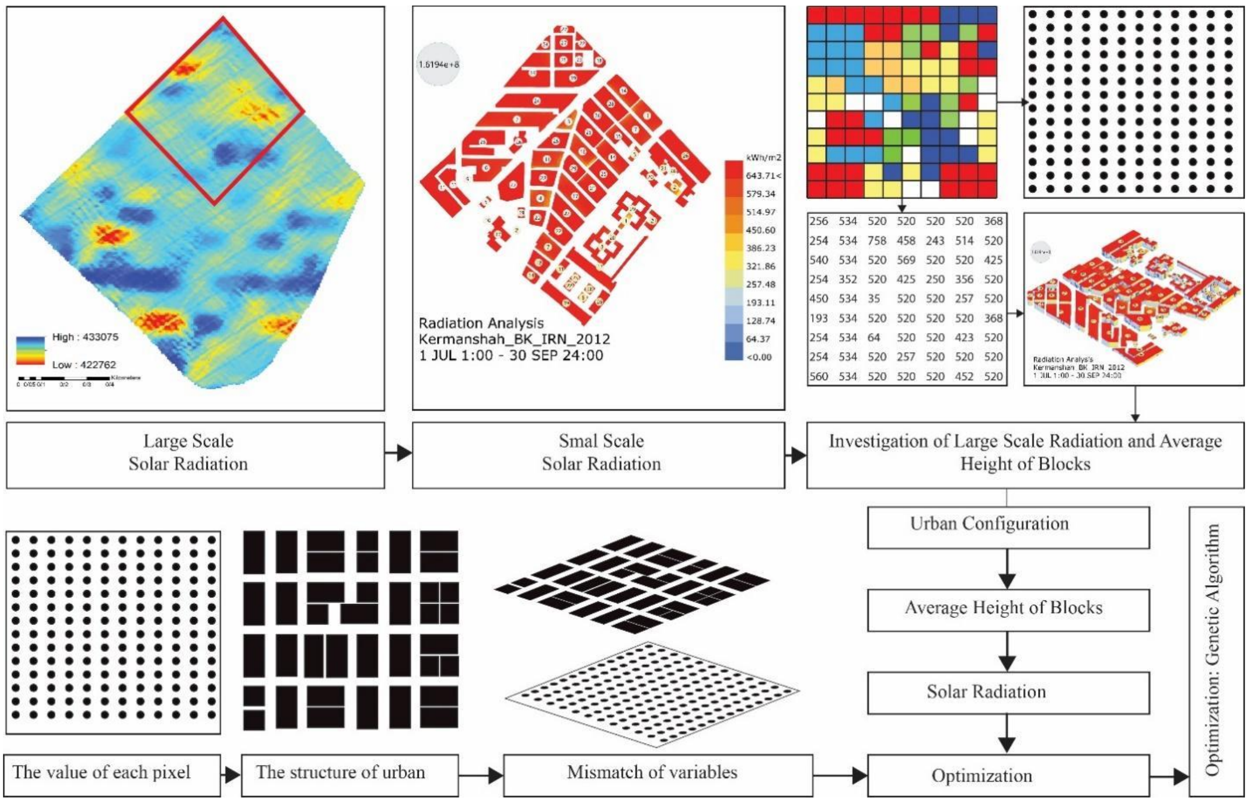

Figure 19: Evaluation of the compatibility of macro data at the satellite level and optimized data based on genetic algorithm

Based on analyses, simultaneous and intelligent use of satellite data in the initial development patterns and matching of height codes with such patterns can help determine the maximum radiation in the urban context. On the other hand, this study shows the need to develop intelligent algorithms based on machine learning algorithms and optimization algorithms in the future. The use of tools and algorithms on this basis can be helpful in the smart development of cities to receive maximum solar radiation and adapt the urban form to other climatic factors.

9. Conclusion

Although City and urban morphology is subject to numerous dependent and independent variables and reviewing and isolating variables in the research process is the only possible solution at this point, research in the field of energy, especially solar radiation, has always been a challenging topic. The need to produce early models of solar radiation levels for a city and ways to access them has been widely discussed. This study suggests a complete model in which the independent variable of average height and a dependent variable of solar radiation and optimization of the research variables were evaluated to achieve an optimal model in which the amount of solar radiation absorption is increased by about 3 to 5%.

The study of simulation at different scales has been assessed in macro and microdomains, each with its algorithm and type of analysis. However, in general, it can be concluded that in the macro-level data used in city planning whose documents and requirements are more related to land use, analyzes and simulations require higher speeds and less information. Thus, the process uses 2.5-dimensional DEM data, either collected through satellite data or point clouds, as fully described in the previous section. However, at the intermediate level, especially at the micro-level, 3D detailed data is needed, which is done using simulation within longer durations with higher accuracy. The only difference between the micro and the intermediate level is the amounts of variables being measured. At the intermediate level, the number of data should be controlled because the amount of data, in this case, is very high, and there may be an increase in computational error. However, in the micro approach, the independent data is lower, and the analysis speed is naturally higher.

The main purpose of this study was to provide an optimal model to evaluate the maximum amount of solar energy absorption at urban block levels. First, the morphological variables at the urban block level were studied. Then solar radiation energy at the macro Scale and micro scales were investigated. Using two radar and point cloud techniques at the macro Scale, solar radiation energy was calculated in the study area, which indicated the importance of macro data analysis at the neighborhood scale. And even urban blocks in the field of planning.

On the other hand, the results showed that radiation data in different seasons produce fixed spatial data compared to each other. The method of calculating radiation time, a significant variable, was also calculated. Then in the next part, the neighborhood was divided into four sub-neighborhoods to measure the impact of different blocks on each other. In this part, optimization was done based on height dimension, indicating that the limitations in optimizer algorithms do not allow the measurement of more variables due to a large amount of information and data. Results on the average height at urban block-level showed an increase of 3 to 5%.

On the other hand, a comprehensive algorithm was presented, starting a new optimization and architectural algorithms approach, which researchers and relevant laboratories can discuss. Adaptation of genetic algorithms to satellite data and spatial variables can help solve significant problems in solar radiation calculation. The first mode shifts the radiation and energy data to point-to-point spatial data, expanding the data beyond the general method for different cities. It opens a new window into artificial intelligence algorithms for a better understanding of the structure of the Earth and its impact on cities.

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