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Energy-Efficient Solutions in The Landscape Design Process

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Abstract

Today, energy-efficient solutions in landscape desıgn are possible through the effective use of natural resources. However, we can meet our energy needs by self-renewing energy sources without consuming natural resources. This study aims to reveal how all the activities involved in the landscape planning and design process are addressed within the framework of energy-efficient solutions. The materials of the study consist of renewable energy sources and other natural resources used in energy-efficient solutions, as well as the resource values that enable sustainable use and the works produced from them. The method of the study presents the traditional landscape design process and the energy-efficient landscape design process, identifying the parameters that define energy-efficient landscape design approaches. Energy-efficient landscape design in urban or rural areas, or open green spaces of various sizes, will ensure the efficient use of energy through the use of plant material potential and geographic data for climate control, creation of shaded and cool areas, well-placed structures, proper material selection, efficient land use, well-applied gardens, and effective agricultural production. To develop a model for energy-efficient landscape design, criteria have been determined regarding the use of solar energy, wind energy, geothermal, and biomass energies in landscape designs. Additionally, the practical and economical use of energy in the design of living and non-living materials, green roofs, green walls, hobby gardens, permaculture gardens, rain gardens, and xeriscape areas has also been considered. In this context, the aim is to create a guide for landscape design processes with these criteria.

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Highlights

Energy solutions in landscape design

Peyzaj Tasarım Sürecinde Enerji Etkin Çözümler

Özet

Günümüzde peyzaj tasarımında enerji etkin çözümler, doğal kaynakların etkin kullanımı ile mümkün olmaktadır. Ancak enerji ihtiyacımızı doğal kaynakları tüketmeden kendini yenileyen enerji kaynakları ile karşılayabiliriz. Bu çalışma, peyzaj planlama ve tasarım sürecinde yer alan tüm faaliyetlerin enerji etkin çözümler çerçevesinde nasıl ele alındığını ortaya koymayı amaçlamaktadır. Çalışmanın materyalini enerji etkin çözümlerde kullanılan yenilenebilir enerji kaynakları ve diğer doğal kaynakların yanı sıra sürdürülebilir kullanımı sağlayan kaynak değerleri ve bunlardan üretilen eserler oluşturmaktadır. Çalışmanın yöntemi, geleneksel peyzaj tasarım süreci ile enerji etkin peyzaj tasarım sürecini ortaya koyarak, enerji etkin peyzaj tasarım yaklaşımlarını tanımlayan parametreleri belirlemektir. Kentsel veya kırsal alanlarda veya çeşitli büyüklükteki açık yeşil alanlarda enerji etkin peyzaj tasarımı, iklim kontrolü için bitki materyali potansiyeli ve coğrafi verilerin kullanılması, gölgeli ve serin alanların oluşturulması, iyi yerleştirilmiş yapılar, doğru malzeme seçimi, verimli arazi kullanımı, iyi uygulanmış bahçeler ve etkin tarımsal üretim yoluyla enerjinin verimli kullanılmasını sağlayacaktır. Enerji verimli peyzaj tasarımı için bir model geliştirmek amacıyla, peyzaj tasarımlarında güneş enerjisi, rüzgar enerjisi, jeotermal ve biyokütle enerjilerinin kullanımının yanı sıra canlı ve cansız materyallerin tasarımında enerjinin pratik ve ekonomik kullanımına ilişkin kriterler belirlenmiştir.

Anahtar Kelimeler

Enerji etkin peyzaj, peyzaj tasarım, peyzaj planlama, enerji

Öne Çıkanlar

Peyzaj Tasarım Sürecinde Enerji Etkin Çözümler

1. Introductıon

In its simplest form, energy is defined as the ability of an object or system of objects to perform work. Energy already exists in nature, and according to the laws of physics, it cannot be created from nothing, nor can existing energy be destroyed. However, it can change from one form to another. This is known as the law of energy conservation, which is the fundamental principle of all energy systems. When energy is added to or removed from a system, the system's properties inevitably change. Energy sources are those from which energy is stored and extracted for direct use or conversion. There are many energy sources on Earth. Energy sources can be classified based on their dependence on the sun, storage capacity, renewability, recyclability, and availability [1].

In energy-efficient landscape design, the goal is to minimize the damage humanity has caused to nature by using renewable energy sources to ensure sustainability. This leads to the creation of healthier, more livable, functional, and aesthetic environments. Traditionally, architectural design criteria were defined in technology, functionality,

aesthetics, and economy. However, these criteria have expanded and transformed with the inclusion of nature, environment, energy, comfort, and energy efficiency. With this shift, functionality is no longer only about shaping designs to be suitable for use but also about ensuring that, while performing its function, the design minimizes harm to nature, is environmentally friendly, produces energy, and is capable of conserving the power it consumes [2].

Energy-efficient landscape design has numerous benefits, ranging from reduced carbon emissions to significant social advantages, such as improving public quality of life and mitigating and preventing ecological damage [3]. Since ancient times, humanity has obtained all the services necessary for life from nature and its resources, creating products that adapt to the environment where people can live safely and comfortably. Designs that meet human needs at the highest level—comfortable, flexible, efficient, environmentally friendly, energy-efficient, and advanced in technology—are always in demand [4]. The presence of energy in every field and the need for effective use of resources have made the efficient use of resources and energy in landscape design increasingly important. Landscape designs must use energy in irrigation, lighting, and urban furniture. This energy use also promotes energy conservation. Research is being conducted in landscape design, where energy-efficient designs are produced using various renewable energy sources.

Energy-efficient landscape arrangements are processes that address the ecosystem as a whole, providing benefits to the environment through microclimate regulation, reducing water consumption by recycling and reusing water, and avoiding the use of petroleum-based materials in environmental design. They also contribute to controlling noise and air pollution, reducing CO2 emissions, and offering economic savings.[5].

Like all other professional disciplines that rely on natural resources, using fossil fuels has increased within landscape architecture. This, in turn, has led to the emergence of issues related to climate change. Reduced energy consumption means lower CO2 emissions. In landscape design processes, choosing building components made of recyclable materials and using fewer fossil fuels in their production can help reduce greenhouse gas emissions. Another aspect that should be considered in landscape architecture regarding CO2 emissions is improper and non-purposeful land use in land-use decisions. Special care should be taken to not disrupt natural ecosystems, especially in large areas. Furthermore, it is essential to dispose of recycling materials properly in landscape design areas. As a result, household waste, paper, and organic materials (such as dry branches, leaves, etc.) can be composted, improving soil fertility and turning accumulated waste into raw material for biomass energy. Thus, the waste management process is handled in a controlled and conscious manner.

In today's world, where usage is increasing and unconscious consumption is on the rise, landscape projects aim to ensure that they are in harmony with natural resources and are sustainable. The unconscious use of resources and consumption-heavy practices have prompted a reevaluation of landscape design approaches. In this context, landscape design processes that integrate natural resources and emphasize sustainable and ecological approaches should be reconsidered. This study highlights the importance of

investigating renewable energy sources in energy-efficient landscape design and using such sources in landscape architecture. It also emphasizes the role of energy-saving applications in designing living and non-living materials, natural resources, and landscape design tools such as green roofs, vertical walls, hobby gardens, xeriscaping, and rain gardens. In this direction, by comparing traditional landscape design processes with energy-efficient landscape design processes, the required parameters for design were determined, and the criteria were evaluated. In energy-efficient landscape design, parameters were identified to develop design models for effective and energy-saving use. Based on the requirements presented, the aim is to create a guide for energy-efficient solutions in the landscape design process.

2. Materials and Methods

The study consists of open-green spaces in landscapes and landscape planning and design works carried out in these areas. In this context, the criteria addressed during the study were determined by examining renewable energy sources used in these processes, energy-efficient landscape design elements, and the values of natural and cultural resources. Additionally, the data sources include theses, articles, reports, observations, and interviews that contributed to the study's supplementary materials.

The research method involved a literature review examining the current landscape design process and existing practices. Field studies were conducted in this context, including data collection, site observations, photography, and visualization. All characteristics of the area, urban improvement elements, materials used, existing topographical solutions, hard and soft landscape areas, and drainage systems were thoroughly analyzed and evaluated.

The methodology followed four stages. These stages were defined based on sources such as asPirselimoğlu et al. 2024; Korkut, 2020 Sağlık et al., 2020 Sağlık, 2020 Sağlık, 2021 Özdemir Işık et al., 2017,[7-11] and other relevant studies. The stages include the existing traditional landscape design process, the development of energy-efficient landscape design processes that incorporate renewable energy, sustainable, and nature-based solutions, the relationship between conventional and energy-efficient landscape design processes, and energy-efficient solutions in landscape architecture. These stages are outlined as follows:

1. Landscape Design: Definition of the problem, data collection, surveys and analyses, site and environmental analysis, site diagram, preliminary project, final project, implementation project (structural implementation project, plant application project).
2. Energy-efficient Landscape Design Process: Integrating energy into the traditional landscape design process creates an energy-efficient framework.
3. Relationship Between Traditional Landscape Design Process and Energy-efficient Landscape Design Process: Identifying the differences between traditional and energy-efficient landscape design processes.

4. Energy-efficient Solutions in Landscape Architecture: Development of example models for energy-efficient solutions and approaches that evolve alongside the landscape design process.

3. Findings

3.1. Landscape Design:

Design, in its broadest definition, can be described as the preparation of an initial form or model, visualizing the shape of a plan or object. Design emerges through the effective use of correct principles and elements. It requires intelligent production that integrates science, engineering, and technology for a specific purpose. The products that emerge from design should be functional, original, tangible, and visual, and they should result from a particular thought process, which includes considering what can be done, documenting it, applying an optimal design process, and considering the design in question [12].

Landscape design aims to achieve sustainability through livable, functional, environmentally friendly, and aesthetically respectful plant-based designs. Aesthetics in design emphasize the attractiveness of the work or product. Functionality depends on the intended use. Landscape design consists of different shapes and forms. It also reflects material and plant diversity. To use this diversity correctly, one must know where and how to use plants and their suitability for specific climates. Projects generally develop based on the principle of sustainability, and designs should be made with this principle in mind. Each design must solve its problems, with the client's expectations, needs, economy, culture, and ecological factors being decisive. However, successful landscape planning and design require specific steps. These steps can be classified into seven main categories: problem definition, data collection, surveys and analyses, site and environmental analysis, site diagram, preliminary project, final project, and implementation applications (Figure 1).

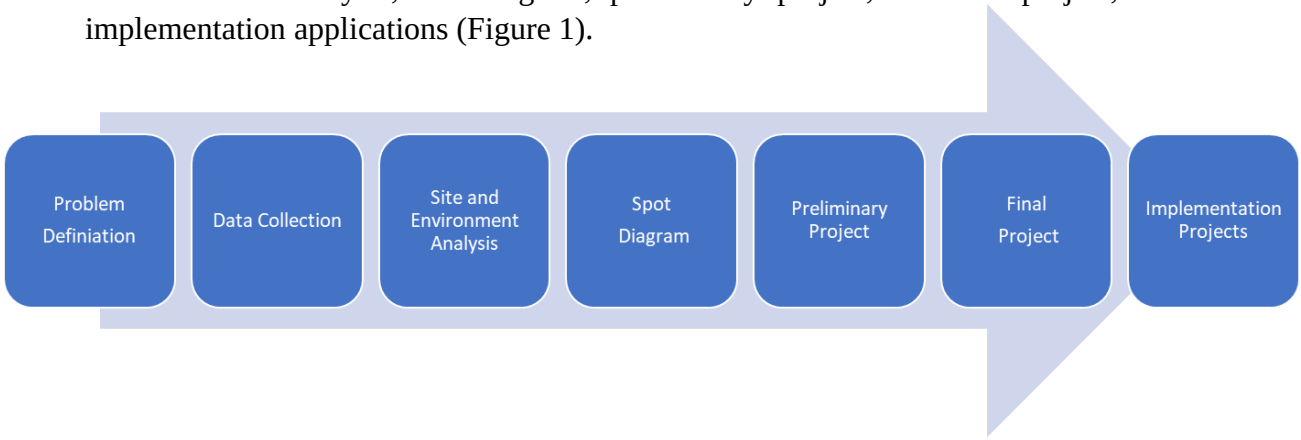

Figure 1. Landscape design process

3.2. Energy-efficient Landscape Design Process

Problem Definition: The existence of a design is only possible when there is an issue or a need to address. This issue is often encountered as a problem; thus, the first step in the design process is defining the problem. In the landscape design phase, issues arise from designs that are not suitable for the land, failure to consider climatic characteristics, not using appropriate plantings for the local area, inability to use local materials, insufficient knowledge about the geographical and geological location of the design area, and during the implementation phase, issues such as failure to preserve existing green spaces, the use of unnecessary construction tools and equipment, excessive water consumption, and the excessive use of lighting units. These factors form the primary source of the problem.

Data Collection (Survey - Literature Review): During the data collection phase, information is gathered from various sources and methods, including maps, measurements, regulations, aerial photographs, satellite images, findings, samples, and individual solutions. The data obtained should include information that allows for a comprehensive understanding of the current status of the natural, cultural, sensory, social, and economic environment.

In this process, it is necessary to research and evaluate all characteristics within and outside the study area. In energy-efficient landscape design, as in traditional landscape design, data must be collected and assessed regarding fundamental factors such as topography, soil structure, climate data (solar radiation, wind, precipitation, humidity, etc.), plant vegetation, land use, existing structures, environmental impacts, and infrastructure. In addition to these factors, in energy-efficient landscape design, the suitability of renewable energy sources should be investigated, the efficient use of water should be considered, and studies should be conducted on the effective use of other potential energy sources. During the research phase, the principle of "protection-use" should be considered for the sustainability of the study area and the design.

Site and Environmental Analysis: This phase involves the analysis of natural and cultural structures in the area and identifying measures that need to be taken to preserve or remove them based on a study produced from all the observations made.

The aim of this analysis is a comprehensive evaluation and analysis of the collected data. These include: Traffic analysis (accessibility, road conditions based on usage intensity, etc.), Slope analysis, Mass and green space analysis, Usage analysis (building function and its reflection on open spaces), User analysis (needs, gender distribution, desires, preferences, traditions, habits), Ecological analysis (climatic analysis, water availability analysis, etc.), Visual analysis (silhouette analysis, building facade characteristic analysis—visual relationships between new and old structures), Infrastructure analysis (drainage, electricity, natural gas systems, sewers, wastewater treatment, stormwater infrastructure, surface water flow), Vegetation analysis (identifying the key topics, features, needs, and values of areas that must be preserved), Relocation, maintenance, and issues related to places to be disregarded [13,14]. These studies, including surface surveys, photographs, maps, graphs, cross-sections, perspectives, and facades, are also

presented in research schedules or on separate pages with symbols and icons in environmental and site analyses.

At this stage, analyses are conducted based on the data obtained from surveys and literature reviews. Additionally, evaluations are made regarding the study and preservation or enhancement of natural landscape features, cultural landscape features, and visual landscape characteristics. As a result of these analyses, the use of renewable energy sources in energy-efficient landscape design is evaluated.

Solar Factor: Solar energy can be harnessed infinitely. In summer, sunlight can serve as a light source, while in winter, it can be used as a heating source. A proper and conscious landscape arrangement can minimize heating and cooling energy loads to zero during summer and winter. The correct use of plants, in particular, can significantly contribute to this process. Some analyses should be made regarding solar energy use. These analyses include determining the seasonal and daily movement of the sun in residential areas, identifying unsuitable landforms that block the sun and wind, avoiding low areas prone to cold air accumulation, and identifying suitable locations for solar energy use. Critical criteria for these analyses [15] include:

- Solar exposure durations by day, month, and year,
- The rate of solar radiation received,
- Good solar exposure on south-facing slopes,
- Maximum sun exposure on west-facing slopes in the afternoon,
- Maximum sun exposure on east-facing slopes for maximum solar gain,
- The primary rock type and depth in the settlement area,
- Areas within a settlement that cannot be built on,
- The type and location of existing vegetation.

Wind Factor: Windbreaks can reduce wind speed both in the wind direction and in the opposite direction. The rate at which a windbreak reduces wind speed depends on the height of the plant barrier and the distance of the protected area from the windbreak. Plant barriers should be placed at a distance of 3 to 7 times the windbreak's height from the protected area for maximum efficiency. Hills, mounds, and other obstacles can be used to redirect the wind. Dense shrubbery can act as a windbreak during winter, while it can serve as a wind channel in summer. Shrubs and trees planted near each other and close to buildings can form windbreaks that block and insulate building walls if they are sufficiently tall. Using plant barriers to redirect the wind can create a pathway for wind, enabling natural ventilation within buildings during summer months. Based on the seasonal wind direction, gaps between windbreaks should be left open to allow the cool breezes needed during the summer to flow into the area. Placing low shrubs, meadows, and ponds in areas exposed to hot summer winds can reduce wind temperatures [16]. Thus, the types of wind entering or existing in the area, the identification of seasonal and daily wind flow patterns around residential areas, and the wind direction analysis should be conducted. Based on these findings, recommendations can be developed for the next phase, and appropriate solutions can be implemented using both living and non-living

materials to take advantage of wind energy. Wind data collected during the survey phase should be assessed in this stage.

Geological Factors: Geothermal system studies, along with geological, hydrogeological, geochemical, and geophysical investigations, should first examine a range of topics such as petrography, volcanology, hydrothermal alteration, structural geology, and environmental geology to create a geological map of the geothermal field. Geothermal surface data and geological parameters controlling the distribution of geothermal resources are crucial for the conceptual modeling geothermal systems. After interpreting detailed geological, geochemical, hydrogeological, and geophysical results, a preliminary assessment of the region's geothermal potential can be made. If the area shows promise for geothermal energy, drilling and reservoir evaluation studies should be planned to determine the drilling sites and geological targets [17]. By evaluating the presence of such areas on landscape features, areas for development and construction can be identified.

Biomass Energy: Biomass fuels, produced by converting agricultural products, household waste, and agricultural industrial by-products into solid, gas, and liquid fuels, can generate heat and electricity [18]. While direct use of biomass energy in landscape architecture is only sometimes feasible, landscapes can be designed to create materials for biomass energy production. In open and natural landscapes, dry leaves, trees, wood fragments, and recycling bins can be incorporated more frequently into projects, contributing to biomass energy production.

In this context, the following analyses are essential for generating energy-efficient solutions with renewable energy sources during the site analysis phase of the landscape design process:

- Climatic factors (precipitation, temperature, humidity, etc.); precipitation, temperature, and humidity graphs should be created and analyzed.
- Topographic features (slope, elevation, etc.); land contour maps, slope, and elevation maps must be produced.
- Soil type, fertility, and depth should be analyzed.
- Vegetation analysis should identify endemic species if present.
- Geological features, such as rock layers and groundwater, should be evaluated, and the "protection-use" principle should be applied if needed.
- Natural disaster areas; should be analyzed.

Program Requirements: In the program analysis, we analyze how the spaces included in the design area will be used according to the purpose and needs of the design. Based on the literature review, the area's current state, the users' needs, and the clients' investments are considered, and flow diagrams showing the potential uses of the area are analyzed. As a result of these analyses, the program requirements identify the spatial uses within the design area. In other words, raw programs are transformed into a needs program due to the program analysis (19). Green roofs, vertical gardens, hobby gardens, permaculture areas, rain gardens, and drought-tolerant landscape elements may be proposed in energy-efficient landscape design. Based on the analyses and evaluations obtained, the needs

program should be developed according to the client's and user's requests and the designer’s recommendations, just as in traditional landscape design.0

Function Diagram: The function diagram ensures the correct placement and relationship of the uses listed in the needs program. Functions that are closely related should be grouped in the same area. For instance, it would not be appropriate to consider a drought-tolerant landscape in a space that features water elements. Instead, spaces that activate the water elements should be designed.

Spot Diagram: In its simplest form, a spot diagram adapts the functional diagram to the design area. At this stage, the spatial uses specified in the program of requirements are placed on the plan as points in appropriate locations, considering their positions within the space, their relationships with each other (functional layout), and their proportions (scale), independently of scale or detail. [19]. The spot diagram is a research phase where decisions regarding the spatial and vegetative solutions of the design are made, transferring the initial concept of the design space into the project.

In traditional and energy-efficient landscape design, the activities grouped in the functional diagram and the corresponding developed areas are related.

Preliminary Project: The design should highlight the region’s natural, cultural, historical, economic, aesthetic, and visual values, as well as its legal, administrative, financial, and technical feasibility [12]. At this stage, the main design decisions are made, and the findings related to the design should be clarified. The objectives of the preliminary project are to outline the structural design and the main lines of the site’s design and construction. In this regard, the integrity and spatial permeability of the area, the continuity of green spaces, the coherence of materials and forms, and characteristic uses and spatial relationships should be considered. However, considering the physical environment data (topography, climate, soil, water, and geological structure), the design should also address sustainable, recyclable, and environmentally friendly spatial design and settlement. Some of these considerations include:

- Designs should be regionally appropriate, using local natural products and plants. Both living and non-living materials should incorporate locally sourced and natural products/materials.
- If there are wetlands in the area, they should be preserved. If they are not active, they should be made functional, and suitable activities should be assigned.
- Choosing darker colors for pavements will increase heat absorption and surface temperatures, promoting the urban heat island effect. Therefore, using lighter materials for pavements is more rational, as they absorb less heat. However, especially in summer, lighter-colored surfaces close to buildings allow more sunlight to reach them due to their higher reflectivity. This enables grass and ground cover to be used close to the building. In areas where pavements should be well-separated from buildings, using materials with higher reflectivity, which can reflect sunlight to the atmosphere, can help reduce the heat island effect.
- Increasing bicycle and pedestrian pathways and providing solutions to encourage their use.

- Reducing lawn and seasonal areas while increasing the use of perennial plants.
- Mulching.
- Composting from waste and trash.
- Ensuring water recycling using intelligent water systems.

Final Project: The final project results from various discussions and revisions, resulting in the approved preliminary projects. Generally, the final project is where ground and level solutions, structural and vegetation placement, transportation axis, and open space designs are finalized. In traditional landscape design, this phase marks the transition of the preliminary design into a full-fledged implementation project.

Implementation Projects: This is the final stage of the project, where the details required for the implementation of the land structure and vegetation design are prepared according to the approved final project. Landscape projects developed with energy-efficient solutions using renewable energy sources should be implemented.

3.3. Evaluation of the Traditional Landscape Design Process and the Energy-Efficient Landscape Design Process

Several differences exist between the traditional landscape design process and the energy-efficient landscape design process (Table 1)[5-11,20-21] . Climatic features are essential in both approaches. However, while the energy-efficient landscape design process emphasizes using renewable energy sources, utilizing natural resources, and using ecological-based approaches, the traditional process tends to prioritize economic considerations, often without focusing on ecological sensitivities.

In energy-efficient landscape design approaches, solutions are developed using renewable energy, sustainable and recyclable materials, local materials, innovative infrastructure, and local plant species in conjunction with nature-based solutions. Techniques such as rain gardens, vertical gardens, green roofs, composting areas, drought-tolerant landscaping solutions, etc., are among the main ecological-based strategies in energy-efficient landscape design.

Table 1. Differences between the traditional and energy-efficient landscape design processes

Landscape Design Criteria	Traditional Landscape Design	Energy Efficient Landscape Design
Climatic characteristics	✓	✓
Use of local materials	X	✓
Biodiversity conservation	X	✓
Use of renewable energy sources	X	✓
Utilising the natural structure of the land	X	✓
Sustainable and recyclable material	X	✓
Use of bicycle and pedestrian routes	✓	✓
Use of grass areas and seasonal plants	✓	X
Use of perennial plants	X	✓
Use of local plants	X	✓
Use of materials such as Polyethylene, Hdpe, Epdm	✓	X
Use of green roof	✓	✓
Vertical garden use,	✓	✓
Having hobby gardens	✓	✓
Presence of rain storage areas	X	✓
Rain gardens	X	✓
Protection of existing plants	X	✓
Composting of garbage	X	✓
Presence of arid landscape	X	✓
Smart irrigation systems	✓	✓
Smart reinforcement elements	X	✓
Smart lighting elements	X	✓
Ecological wildlife	X	✓

3.4. Energy efficient solutions in Landscape Design Projects/Applications

In energy-efficient landscape design, after the analysis and evaluation of the area by the designer, other factors should also be considered, and during the design phase, energy-efficient design parameters should be incorporated to guide the design.

Landscape designs that contribute to energy savings can also be regarded as sustainable designs. From this perspective, energy-efficient landscape design is a crucial approach. The rapid spread of technology, the increasing emphasis on the efficient use of energy and resources, and environmental protection have become complementary and interacting elements in today's developing world. In this context, energy sources can be utilized for extended periods, allowing them to be passed on to future generations. Therefore, using renewable energy sources in landscape architecture should be expanded, and designs

should incorporate opportunities for renewable energy sources. In landscape designs, the energy-efficient landscape design process has been defined by integrating renewable energy sources. This process is illustrated in Figure 2.

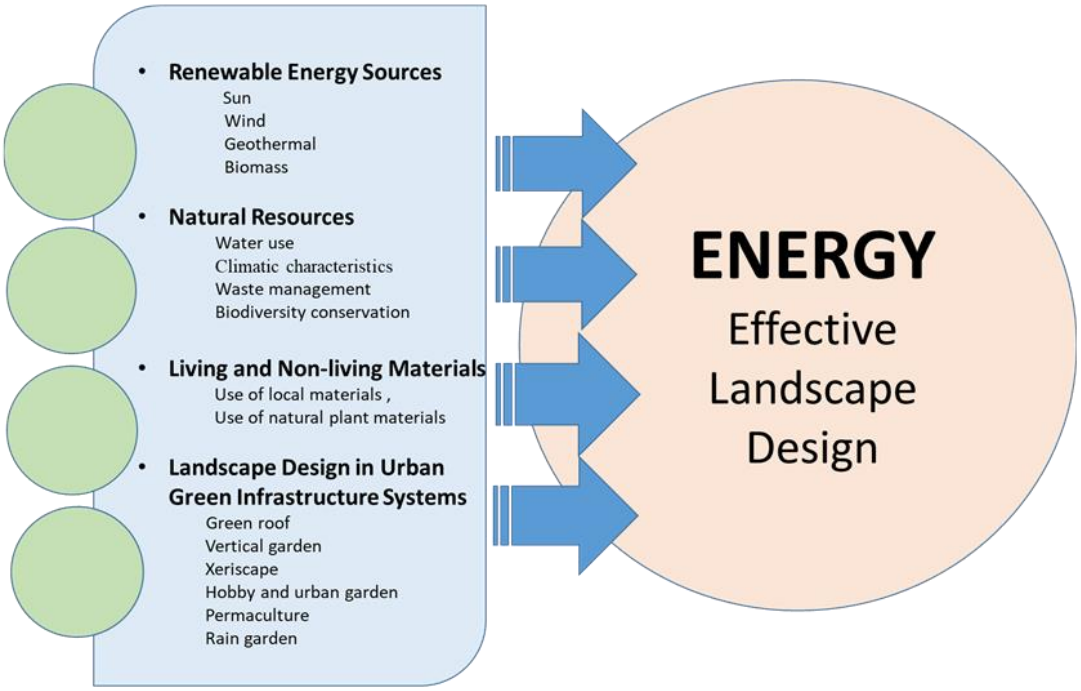

Figure 2. Energy-efficient landscape design

Landscape Design with Renewable Energy Sources:

Solar Energy: Using solar energy outside buildings provides a creative expression to the spaces in which it is applied and helps raise awareness about these technologies among the public. Photovoltaic solar energy systems can be seen in many public spaces in cities worldwide. These systems are used in buildings for various purposes such as environmental protection, economic benefits, energy conservation, and prestige; however, they are also employed outside buildings [21]. As a shading element, such systems can be found in gas stations, bus stops, telephone booths, parking areas, information kiosks, restrooms, and parking lots (Figure 3) (Table 2).

Figure 3. Living unit developed with solar Energy

Table 2. Relation of renewable energy sources with landscape architecture

NEW RENEWABLE ENERGY SOURCES	ENERGY SOURCE THAT CAN BE USED IN LANDSCAPE ARCHITECTURE	USAGE PURPOSES IN LANDSCAPE ARCHITECTURE	AREAS OF USE IN LANDSCAPE ARCHITECTURE
Solar energy	Solar energy	Eaves (shading) element	Gas station
			Bus stops
			Telephone booths
			Information stands
			Car parking areas
			Public toilets
Wind energy		Outdoor lighting element	Street lighting
			Motorway, street lighting
			Advertising billboards
			Park and garden lighting
			Holiday villages and hotel lighting
			Site outdoor lighting
Biomass energy		Sound barrier system	Sound barrier
Geothermal energy		Heating system	Greenhouse cultivation
			Drying of agricultural products
			Heating of domestic water
Hydrogen energy		Urban furniture	Seating elements
			Telephone charging units
Wave and current (tidal) energy			Wifi stations
		Irrigation systems	Agricultural irrigation
Hydroelectric power			Rainwater storage
	Wind energy	Outdoor lighting element	Street lighting
			Motorway, street lighting
	Biomass energy	Natural fertilisation	Dried vegetation
			Household waste
			All natural ingredients
Hydroelectric power	Geothermal energy	Heating system	Greenhouse cultivation
			Heating of domestic water

Wind Energy: In landscape architecture, wind energy, although less prevalent than solar energy, is utilized in various applications. These include using wind energy for lighting in areas such as highways and urban parks and in seating units where wind energy can be harnessed.

Biomass Energy: When considering its applications in landscape architecture, biomass energy is effectively utilized in forest landscapes. Forest and agricultural waste, as well as pulp and paper waste, can be converted into heat and electricity in an environmentally friendly manner. Combustion is the most commonly used thermal process for biomass. Burning helps convert the chemical energy stored in biomass into heat, mechanical, or electrical power. Any biomass can be burned; however, sources with moisture content greater than 50% require pre-drying, so direct combustion is not preferred for these materials.

Geothermal Energy: Geothermal energy is significant in landscape architecture due to its geological structure, unlike other renewable energy sources. This energy source must be structurally suitable for geothermal utilization. In Turkey, many geothermal resources exist in regions such as the Aegean, Northwest, and Central Anatolia, located along active fault lines in the orogenic belt. Geothermal energy is primarily used in landscape architecture for purposes such as greenhouse cultivation.

Landscape Design with Natural Resources:

Water Use: One of the critical considerations in water-related design is the selection of appropriate irrigation systems and regimes and the evaluation of wastewater's potential

use for irrigation. Ensuring the most efficient use of the natural water cycle is essential. This approach is vital for both structural and plant-based landscape arrangements. Additionally, irrigation-based energy-efficient solutions are also implemented in landscape projects. According to Hakgören, irrigation can generally deliver water to the soil in various forms to support plant growth, especially when water is not naturally available during the growing season. As the definition suggests, there are three critical factors in irrigation: water, soil, and plants. The success of irrigation largely depends on managing the relationships among these factors optimally to ensure continuous crop production [22]. Water constitutes a significant portion of the plant's structure, with about 85-90% of a living plant's mass being water. In other words, water is a vital liquid that sustains life and is necessary for the chemical processes that support plant growth and nutrient production.

Effective irrigation methods are crucial for the efficient use of outdoor water, and these methods can be applied to all types of landscapes, including traditional or xeriscape designs. Therefore, it is critical to develop the most suitable irrigation system based on the size of the area, its intended use, and the environmental context. This requires thorough preliminary research and the creation of an irrigation project under expert supervision [23]. Irrigation-based energy-saving solutions, such as rainwater harvesting, regulate air humidity and provide cooling effects during hot summer while preventing continuous water usage in hydrophilic plants.

Climatic Characteristics: Climatic conditions are one of the most critical factors in landscape design. Both structural and plant-based landscape design are significantly influenced by climate. Plants are the most utilized factor by landscape designers, and the most influential factor in plant development is climate. Outdoor applications are subject to climatic factors (precipitation, temperature, humidity, wind) for decades. Therefore, when selecting plants for a design, it is essential to consider how the climate will change over the coming decades and how these changes will affect plants. Similarly, factors such as precipitation, temperature, humidity, and wind are also considered in structural landscape design. The location of spaces, the materials and equipment to be used, and other design elements are closely related to climatic factors.

One of the predictions of climate change is an increase in heatwaves. Landscape architects can create relaxed environments for people on hot summer days by emphasizing shade-providing plants. Active green spaces in cities can be expanded to develop areas where urban residents can breathe, and spaces can be designed as refuges from the summer heat.

Waste Management: In energy-efficient landscape design areas, the proper segregation of recycling materials should be ensured. As a result, household waste, paper, and natural organic materials (such as dried branches, leaves, etc.) can be composted, improving soil fertility and generating raw materials for biomass energy. This waste management method is conducted in a controlled and conscious manner.

Biodiversity Conservation: Another vital aspect is the need to protect endemic species in the face of climate change, which is expected to reduce biodiversity. Urbanization, road construction, and fences may not directly result from climate change but can create

ecological corridors between fragmented habitats. Similarly, ponds and bird baths can be made to protect wildlife, and fruit trees can be incorporated into designs. An approach that minimizes habitat fragmentation or creates corridors should be adopted when designing roads. Additionally, considering the increase in floods, measures should be taken to protect river ecosystems and mitigate the effects of flooding. In landscape planning and design, the natural species of the region should be prioritized while creating green textures.

Energy-efficient urban or rural landscapes and open, green spaces of various sizes utilize plant material potential and geographical data to create climate control, shade, and cool areas. Well-positioned structures, the correct selection of materials, efficient use of land, and the inclusion of gardens or agricultural production can ensure the efficient use of energy. When designing new residential areas or buildings with various functions or relocating existing environments, gardens and courtyards should be considered.

Landscape Design with Living and Non-living Materials

Structural Landscape-based Energy-Efficient Solutions: Landscape structural elements are implemented by determining the components of materials such as wood, natural stone, and urban furniture systems to be used. Pedestrian pathways, water elements, curtain walls, stone walls, gabions, sports field tension systems, and children's playgrounds constitute the spatial structure of the landscape. When we examine structural landscape, areas, streets, and roads serve as urban routes where people walk or travel in vehicles. Traffic is the key factor that facilitates the movement of people and the city between blocks. Moreover, they serve as connectors between different functional areas. Squares and resting areas are the city’s passive zones, providing space for rest and gatherings. These areas serve as spaces for socializing, as they slightly slow down the rapid traffic flow on streets and avenues. Shopping areas are physical spaces where shopping activities occur. These include open markets, areas surrounded by shops, and shopping centers. Parks are classified into different categories based on their size, the variety of activities they host, their impact areas, and the population they serve [24,2]. Generally, they represent areas that are part of green and nature. Green spaces are critical in urbanized areas. Children's playgrounds are spaces that meet the needs of children for fresh air, play, and social interaction. The materials used in playground equipment should help children connect with and experience nature. In the energy-efficient landscape design model, the aim is to design and implement these spaces to minimize environmental impact. In this context, in addition to traditional landscape design, energy-efficient solutions allow landscape architects to create more environmentally friendly designs. Ultimately, we are transforming natural spaces and the areas we live in and use into more sustainable environments. In landscape architecture, we can make the spaces we design and implement more energy-efficient using the following criteria:

- **Preservation of existing landscape character**: The local features of the working area, including cultural and geographical characteristics, should be preserved.
- **Aesthetic integration with the natural structure of the area**: Maintaining the characteristics of the natural environment during design work also facilitates cost savings for the client.

- **Efficient use of natural resources**: Design solutions should enable the effective use of existing vegetation, waterways, flora, fauna, etc.
- **Development and utilization of natural resources**: Green standards for central business districts should be maximized where possible, and high green coverage should be maintained in squares, event spaces, and buildings.
- **Activity suitability and ecological fit**: Activities should be in harmony with the area's regional social needs and environmental structure. Detailed surveys and analysis of the site should be conducted. For example, sloped surfaces and mounded structures should be preferred in areas with high rainfall, as stagnant water can reduce usable space.
- **Incorporation of historical and cultural values**: The cultural characteristics of the area to be worked on should be well understood, and elements reflecting these values can be integrated into urban green infrastructure systems, such as in city squares, public building entrances, children's playgrounds, and urban furniture.
- **Effective use of microclimatic data**: Climatic data such as sunlight, wind directions, temperature, and radiation should be used effectively in planning, urban design, and architecture to achieve energy efficiency and conservation.
- **Efficient use of topographical data**: Minimize infrastructure and superstructure problems arising from the terrain. The geological structure of the construction site, soil capacity, and fertile lands should be moved to green areas and utilized effectively.
- **Use of sustainable paving materials**: Paving materials should be recyclable, easy to transport, readily available, and locally sourced to reduce supply costs and promote environmental benefits. As with all urban landscapes, locality, transportability, and recyclability are critical criteria in pavement selection. Natural products such as sand, wood chips, or soil should be used in energy-efficient children's playgrounds for ground covering.
- **Urban furniture made from natural materials**: Furniture in these areas can be produced from natural materials, and landscape elements can be designed to harness renewable energy. For example, playground equipment can be made from natural wood or tree trunks, shaped and used naturally. Instead of synthetic materials such as HDPE or polyethylene, recyclable materials like metal and wood should be preferred. These materials are cost-effective but should be avoided in landscape elements due to their negative environmental and health impacts.
- **Lighting elements in streets and highways**: Lighting fixtures can generate solar and wind energy. Lighting infrastructure can be self-sustaining by using solar panels and wind turbines. Solar energy, wind energy, and shading elements can also be utilized in seating units, urban furniture, and Wi-Fi charging stations.
- **Increasing green areas instead of hard surfaces between buildings**: Green spaces should replace hard surfaces between buildings. Planting trees along roads and using living materials in transportation corridors should be prioritized.
- **Emphasis on bicycle and pedestrian paths**: Designated areas for bicycles and walking should be given priority. Spaces free from motorized vehicles should be favored.
- **Incorporating renewable energy into event spaces**: Solar panels and wind turbines can be placed on roof coverings, lids, and other fixtures to generate power.

- **Use of water features and biological ponds in urban green infrastructure**: Urban green spaces such as squares and parks can include water features and biological ponds, thus providing natural spaces for other organisms in the ecosystem.
- **Energy and waste recovery in city centers**: Electric power, solar energy, natural gas, etc., are used in the central business and residential areas for energy recovery. Technologies related to energy recycling should be used, and waste (solid/liquid waste, biological waste, etc.) should be segregated on-site with recycling technologies.
- **Biomass energy should be used in green infrastructure** in event spaces and green infrastructure areas.

Plant-Based Landscape Energy-Efficient Solutions: In landscape architecture, planting design is an essential step in the landscape design process. Plants perform various functions in landscape designs, such as creating space, connecting (integrating), enclosing, ensuring privacy (protection), completing, merging, enhancing, multiplying, blurring, and framing. Additionally, plants can be used around buildings, in gaps between buildings, and open spaces, integrating with other landscape elements [25]. Furthermore, some energy-saving solutions can be listed as follows [26-29]:

- Ecological Context: Planting design should be done according to local ecological conditions (topography, soil, microclimate, etc.).
- Use of Local Resources: In ecological and climate-appropriate planting designs, it is essential to use local resources. The use of native plant species, their adaptability to the site, availability, and mobility are key factors.
- Support for Local Flora: It is necessary to support the existing vegetation to develop and study region-specific plant species.
- Use of Local and Adapted Plants: The first consideration should be using local and adapted plants when designing green landscapes.
- Advantages of Native and Adapted Plants: The main advantage of using native and adapted plants is that they require less water and maintenance. In this way, they help conserve the existing flora and ensure its sustainability.
- Water-Efficient Solutions: In energy-efficient planting designs, minimal water solutions are prioritized.
- Purpose of Energy-Efficient Plant Species: The purpose for which energy-efficient plant species are used in plant-based landscapes is crucial. For instance, in winter, broadleaf plants around a building allow sunlight to reach the building, while in summer, the same plants provide shade and offer cooling. This way, a natural energy source like the sun is used at zero cost.
- Plants and Rainfall Control: Plants also can regulate rainfall and humidity in the atmosphere and on the ground. Broadleaf, needle-like leaves, branches, twigs, and stems capture, trap, and filter precipitation.
- Creating Ecosystems: Different vegetation and soil cover are essential for creating natural habitats. Plants provide shelter and produce various food sources, such as seeds, fruits, and buds, which create a favorable environment for wildlife.
- Organic Fertilizer Production: Another plant-based energy-saving solution is the creation of organic fertilizers.

Landscape Design in Urban Green Infrastructure Systems:

Green Roofs: Installing a green roof system on a building can reduce energy consumption for heating in winter and cooling in summer, which leads to cost reductions. The green roof includes plants, soil, and other materials. Thanks to the layers in its structure, it also performs insulation and isolation functions. On average, these green roofs are 10% more efficient than conventional roofs [30]. Green roofs are one of the best solutions to provide green space in response to increasing urbanization. They hold significant ecological and aesthetic value in urban landscapes. Green roofs trap sunlight and prevent heat reflection.

Vertical Gardens: Facade gardens, which offer aesthetic, social, and ecological advantages in public and private spaces, introduce changes in design concepts. The greening of facades not only positively contributes to the environment but also reduces heat transfer between the building and its surroundings, thus contributing to the passive climate control of buildings in the long term [31]. Green walls, in energy-efficient landscapes, particularly in urban settings, play a key role. Green walls help maintain the thermal balance of the city by keeping buildings cool in the summer and warm in the winter. They also assist in keeping the surrounding area warm.

Xeriscaping in Hobby Gardens: Due to the high water consumption in outdoor spaces like parks and gardens, it has become necessary to develop new areas that use as little water as possible. In this regard, concepts like "Water-Efficient Landscaping," "Water-Wise, Water-Smart," "Low-Water," and "Natural Landscaping" (which differ from classical landscaping concepts like natural landscapes) have been formulated under the general term “Xeriscape.” Xeriscaping is typically defined as a landscaping approach aiming to conserve water resources and the environment by using minimal water [32].
Xeriscaping, as opposed to traditional landscaping, involves several approaches, such as: Reducing Soil Erosion and Water Loss: Through careful planning, design, and implementation, soil erosion and water loss can be minimized.

Limiting Lawn Areas: The size of grass areas is reduced since grass growth can be managed with appropriate fertilization techniques.
Minimizing Fertilizer Use: Reducing fertilization associated with soil processing.
Selecting Appropriate Plants: By choosing the right plants, irrigation and fertilization can be minimized, and pruning of trees and shrubs can be reduced.
Reducing Replanting: Proper soil treatment and plant selection can minimize the need for replanting.
Reducing Weeds: Proper mulching can help reduce weeds.
Reducing Pests and Diseases: Appropriate maintenance and healthy root formation help reduce water usage and the occurrence of pests and diseases.
Site Selection: Choosing appropriate sites and planting drought-tolerant plants around buildings can help reduce the damage caused by watering structures and foundations.

Rain Gardens: Rain gardens are shallow depressions where rainwater is directed without treatment, and plants naturally grow. They are an intelligent, strategic, and aesthetic model based on water filtration in low-lying areas. The soil in these gardens functions like a sponge, absorbing the water. In other words, they can be seen as depressions where natural plants with deep root systems grow. It is possible to implement such systems in

areas with impervious surfaces, such as vehicle traffic areas, parking lots, specific sidewalk points, and certain parts of the streets to collect rainwater [33].

Permaculture: Permaculture is a concept focused on sustainable living for people in rural and urban areas [34]. The aim is to propose the most effective solutions considering the environment's ecological, health, and economic aspects. To offer reasonable and appropriate solutions, the structural features of the topography and the natural characteristics of the area's flora and fauna must be thoroughly considered [35]. Suitable urban areas should be transformed into spaces for sustainable agriculture or aquaculture based on the functioning of natural ecosystems.

Hobby and Urban Gardens: Hobby gardens are essential to the ecological resources within urban open green space systems, providing a balance between plants and structures. These spaces are crucial not only for meeting the recreational needs of people but also for contributing actively to urban ecology and aesthetics without imposing additional costs or financial burdens [36].

4.Discussion and Conclusion

Today, energy is the most critical need for all aspects of the daily lives of living organisms, but obtaining and using energy in ways that do not threaten the environment remains one of the most significant challenges for societies. The two primary sources of energy supply are fossil fuels and renewable resources. In developed countries, most energy is derived from fossil fuels, and the damage caused by their impact on nature is often overlooked. Energy shortages resulting from irregular energy sources are affecting social relationships and even world peace. Over the years, realizing that the environment has been irreversibly damaged due to this careless use has prompted the search for the most effective solutions, including energy-saving measures in various fields.

The search for renewable, reusable energy sources has emerged to transfer our rapidly depleting natural resources to future generations. This rapid consumption is evident not only in all sectors but also in landscape architecture. Moreover, in landscape architecture, areas should be designed to use less energy and adopt sustainable energy sources that can be reused, along with solutions for more efficient energy use.

If renewable energy sources support the energy required for landscape applications, there is a higher likelihood that the design will be environmentally friendly and sustainable. The goal of energy-efficient landscape design is to create sound designs that minimize damage to the energy consumed and the energy source while adapting to climate and environmental conditions without harming nature through waste generated during the planning and usage processes.

Energy-efficient landscapes aim to improve environmental quality by increasing natural factors, from inanimate materials used in the area to the living materials involved, rather than relying only on renewable energy sources. The fundamental principles should be to reduce energy consumption costs related to shading, irrigation, and lighting in landscape

design, reduce reliance on fossil fuels, minimize costs and maintenance efforts, and ensure that landscape applications contribute to nature, ecosystems, and human health. A well-designed landscape enhances aesthetic quality and supports numerous systems through efficient energy use.

Landscape architects aim to reduce fossil fuel consumption by incorporating renewable energy sources into their designs. Various solutions are being developed at different landscape design points through solar, wind, biomass, and geothermal energy. Several examples of such projects exist, such as the "glowing bicycle path" in the Netherlands, which uses solar power, and the "wind tree" in France, which uses wind energy, both utilizing renewable energy sources. Based on these approaches, both structural and plant-based solutions are being developed. Another approach to reducing fossil fuel consumption is prioritizing using organic fertilizers over chemical fertilizers to fertilize green spaces. The production of chemical fertilizers consumes large amounts of fossil fuels. Organic waste from maintenance practices can be composted and used as fertilizer, reducing the need for chemical fertilizers and, consequently, the consumption of fossil fuels. Moreover, using compost increases the carbon storage in soil, enhances its nutritional capacity, and improves its water retention capacity. When planning, lawns and composting facilities should be considered together. The use of peat in landscaping should also be avoided or reduced, as peatlands, where peat forms, are natural carbon reservoirs that store carbon. Using compost made from organic waste instead of peat in crop cultivation reduces greenhouse gas emissions.

Green roof systems and applications such as vertical gardens also contribute to lowering surface temperatures through their effects of evapotranspiration and shading. Studies by Alexandra and Jones (2008) noted that temperature reductions of up to 8.4°C could be achieved by covering heat-absorbing surfaces with vertical gardens to provide evaporative cooling. Thermographic measurements on traditional ivy-covered facades indicated temperature changes of up to 5°C due to heat insulation in winter and summer [37]. Green walls also serve as a natural air conditioning system, reducing the building's energy operating costs. Due to the many benefits they provide, they are of significant value for a sustainable future [38]. Since 1996, the effects of vertical garden systems on surface temperature in various environments have been studied at the University of Toronto. Walls covered with urban vertical garden canopies are generally more relaxed than walls made of bright tiles, bricks, and black surfaces [39]. These studies have demonstrated that vegetation can reduce daily temperature fluctuations by up to 50% by protecting walls from the sun and significantly lowering the maximum building temperature.

A study conducted in the Parade of Homes development area in Manhattan, Kansas, USA, found that some Houses were more energy-efficient, with lower energy costs due to specific locations. The results indicated that houses with environmental adaptations, such as external shading devices or strategic plantings, or those with functional landscape designs, were more likely to be energy-efficient [40]. Moreover, the proper use of plant-based content can reduce energy usage. The appropriate selection and placement of plant materials control factors such as shade, cold wind tunnels, winter winds, and sunlight

[40]. In addition, when considering plant selection in landscape designs, Zencirkiran and Akdeniz (2017) and Seyidoğlu et al. (2017) highlighted that selecting plant taxa with low water consumption and high tolerance to factors such as heat, drought, frost, pollution, salt, and wind, along with using a higher percentage of native plant species from the local flora, will significantly contribute to the sustainability of urban green spaces. Therefore, these factors must be considered in future designs, and a higher proportion of plants with suitable ecological tolerance should be utilized [41-42].

In structural landscape designs, using local, recyclable, reusable materials with low maintenance costs should be prioritized, and possibilities for reusing existing materials should be explored.

In landscape architecture practices, the area's current conditions must be considered. Existing plants should be identified, and design decisions should be made regarding their preservation and use. Plants suited to the land conditions, requiring minimal maintenance, and offering continuity should be preferred over exotic plants that require high levels of care and are costly. This approach eliminates the need for chemical fertilizers and harmful pesticides. Furthermore, instead of placing expansive lawns and seasonal plants, a dry landscape approach should be preferred, which requires minimal water or maintenance and uses water efficiently. A green strip should be created between boulevards and sidewalks to contribute to the need for more green spaces in the city.

Conflict of Interest

There is no conflict of interest regarding this article.

Author Contribution

The authors have contributed equally.

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