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Review Article

Optimization of Energy in Sustainable Architecture and Green Roofs in Construction: A Review of Challenges and Advantages

Sara ziaee,[1] Zeynab Gholampour,[2] Mina Soleymani,[3] Parisa Doraj,[4] Omid Hossein Eskandani,[4] and Samireh Kadaei[5]

[1]*Department of Architecture, Islamic Azad University West Tehran Branch, Bachelor of Architecture Engineering, Tehran, Iran*
[2]*Department of Art and Architecture, Payame Noor University, Shiraz, Iran*
[3]*Urban Development Department, Fine Arts School, University of Tehran, Tehran, Iran*
[4]*Department of Architecture, Faculty of Architecture and Design, Ataturk University, Erzurum, Turkey*
[5]*Department of Architecture, Faculty of Art and Architecture, Central Tehran Branch, Islamic Azad University, Iran*

Correspondence should be addressed to Samireh Kadaei; samira.kadaei@gmail.com

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Sustainability has been one of architecture's most significant trends over the last twenty years. The environmental consciousness of professionals has put sustainability at the heart of the architectural profession and has contributed to adopting and implementing sustainable designs on the scale of urban landscapes. A green roof or living roof, which is a sustainable solution in architecture, is a roof on the surface of which plants are grown. The roof is covered by plants, covering the waterproof layer beneath the vegetation. However, various types of plants can be used in this scheme. Understanding the influencing factors in choosing the right plant species and the impact that utilizing green roofs has on the overall energy consumption of the building can tremendously help scientists and clarify the possible future research topics in this field. Hence, this article investigates energy optimization in the construction process of a green roof in sustainable architecture and its advantages and challenges. The results of this study show that budget limitations, managerial and organizational policies, legal issues, technical and scientific infrastructure, and cultural and geographical aspects are all affecting the widespread use of green roofs currently and need to be considered in future studies.

1. Introduction

The geographical expansion of cities has led to the destruction of natural environments and agricultural lands. Some anthropogenic activities may result in deleterious effects on environmental elements. Issues such as air and water pollution and depletion of natural resources are deteriorating the earth's ecosystem [1]. The urban system and its correlation with varying environmental needs may lead to catastrophic consequences such as reshaped societies and environment [2]. The degradation of the land leads to biodiversity loss and decreases public animal and human health. For sustainable wildlife, the conservation technique needs new strategies and innovation including analyses on the carbon and greenhouse gas emissions as well as ecological monitoring, which is carried out to evaluate climate change effects [3]. Some solutions have been proposed to reduce these destructive effects. These solutions are known as green property development which includes passive design methods such as wall insulation, low E-window, and solar heating systems. Such solutions have evolved as a potential choice for different types of environments [4]. Additionally, many new technologies and activities have been developed to reduce the human impact on the earth, including alternative energy resources, efficient use of natural resources, sustainable agriculture, and green spaces [5–7].

The creation and development of green spaces play an essential role in human life and are considered a substitute for the natural environment that is lost during construction [8]. Roofs can be utilized as hosts for green spaces [9]. In urban buildings, flat roofs are designed at a high cost to protect the building from rain and snow and store mechanical equipment [10]. Flat roofs usually lack architectural aesthetics and, therefore, cannot enrich the aesthetic and architectural value of the building. These rough surfaces give the building area and the city, as a whole, an unpleasant look. Today's apartment dwellers try to return the spirit of the nature to the rough residential blocks by connecting the living and green nature with the modern technology and create beautiful and original landscapes [11]. Also, the land is scarce and very expensive to create green spaces in cities. Hence, green roofs are part of the efforts of city managers to stabilize the urban space by expanding the green space to buildings and are among the modern strategies for addressing urban environmental issues [12, 13]. Many countries have considered using a vegetation layer on the roof of residential units, office buildings, educational, medical, pilgrimage, recreational, and sports spaces in urban areas [14].

Modern green roofs, which are essentially prefabricated layered systems, are relatively new. They were developed in Germany in the 1960s and have been common in some other European countries as well [15]. Although these roofs are quite common in northern Europe, such as the Scandinavian countries, the Netherlands, and Scotland, their modern, urban form was born in Germany. Today, it is estimated that about 10% of all German roofs are green [16]. Developed countries have long been at the forefront of utilizing green roofs, which serve the development of green spaces in metropolitan areas [17]. A green roof is an interconnected complex system of the following items: a waterproof insulation covering the roof, a well-proportioned vegetation layer, and a proper drainage layer.

One of the main concerns regarding the sustainability of cities is the increasing trend of domestic and industrial energy consumption and its adverse effects and irreparable damage to the natural environment. Utilizing green roofs has been one of the choices for reducing building energy usage [18]. If properly designed and implemented by taking climate considerations into account, green roofs can greatly help reduce energy consumption [19]. Creating greenery in the roof space has a positive effect on cooling the city's climate and the indoor air of the building on which they are located by blocking sunlight and reducing surface evaporation and transpiration [20]. The cooling is carried out by reducing heat fluctuations on the roof's outer surface and increasing the roof's heat capacity, which keeps the space under the roof cool in summer and maintains a moderate temperature during winter [21]. Other benefits of utilizing a green roof include noise and air pollution reduction, urban heat island mitigation, support of biodiversity, and management of stormwater. Furthermore, they may lead to an increase in the lifespan of roof materials [22]. Additionally, these roofs are a good alternative for enjoying the green space in the environment [23–25].

Green roof execution knowledge does not vary much from ordinary roofs and includes thermal insulation, thermal waterproofing, sand, and sealant [10]. Under the requirements specified in the house, green roof projects include materials and elements that could provide moist maintenance/drainage and plant maintenance. However, a green roof is partly or entirely filled by biomass or a growing medium [12, 15, 17], which makes its design and maintenance more complicated than normal flat roofs. Green roofs require plants that can withstand the harsh and lifeless environment of the roof in conditions of dehydration, frost, storms, etc. The type of plant selected varies depending on the climate and climatic conditions [26, 27]. Conducting a comprehensive investigation into green roofs can tremendously help researchers identify possible research and experimental topics as well as future trends in this field.

Table 1: The number of selected studies for each journal.

Journal	#
Current Opinion in Environmental Sustainability	24
Sustainability	53
International Journal of Sustainability in Higher Education	42
Environmental Advances	2
Environmental Challenges	1
Environmental Development	8
Energy	11
Energy and Buildings	73
Urban Forestry & Urban Greening	65
Science of the Total Environment	38
Journal of Environmental Management	22
Urban Forestry & Urban Greening	66
Hellion	1
Building and Environment	57
Construction and Building Materials	5
Sustainable Cities and Society	12
Renewable and Sustainable Energy Reviews	11
Journal of Cleaner Production	21

Accordingly, this paper investigates the concept of green roofs and sustainable construction and their advantages and challenges. The primary purpose of this study is to investigate the environmental benefits of green roofs and their effects on urban residents as well as the challenges of their construction using a descriptive-analytical method. To comprehend green roof technology, the analysis in this research offers the general consumer an informative overview of green roof technology. This analysis also describes in depth each part of the green roof, its advantages, and the challenges in utilizing it.

The rest of this article is structured as follows. The next section reviews the most prominent studies on green roofs. Section 3 focuses on the benefits of green roofs and how they contribute to the sustainability of the building as well as the whole urban area. Section 4 discusses the challenges of using green roofs and their current downsides, which need to be addressed in further studies. Finally, the conclusion is presented in Section 5.

2. Literature Review

To gain a comprehensive understanding of the studies that have been conducted on green roofs and sustainable architecture as a whole, this section reviews the most prominent research that has been conducted in this field. First, the review materials and methods are discussed in the next

Table 2: Keywords of some research used in the current research in the field of green roof.

	Keywords	N
1	Green roof technology	15
2	Green roof structure	17
3	Green roof components	11
4	Green roof benefits	8
5	Roof garden	6
6	Green roof and energy consumption	27
7	Green roof policies	3
8	Green roof advantages	28
9	Green roof challenges	31
10	Green roof implementation	12

section. Then, the types of green roofs and the general classification of green roof components in the literature are discussed in detail in the following two sections.

2.1. Materials and Methods. There have been more than 28,000 scholarly research studies on green roofs since before the 19th century. In this section, international research articles from different sources, i.e., scientific studies, books, case studies, and reports, are reviewed. First, the indexes of journals were searched to identify some related journals, such as Science Direct, Scimagojr, and Scopus. Then, we searched for the desired keyword (green roof) on the sites of each journal to determine the number of articles in each journal separately. Table 1 reports the results of this search.

Then, article search platforms such as Scopus, Web of Science, Google Scholar, and Science Direct were searched for a list of relevant keywords which are tabulated in Table 2. Several articles are stored in the library. Similar or non-accessible articles were then removed from the library.

Figure 1 shows the percentage of studies for different green roof-related keywords. The statistics from the Science Direct site show that the amount of research studies in the field of green roofs is increasing. Table 3 reports the number of articles and research studies about green roofs. Also, Figure 2 reports the number of research studies on green roofs every seven years starting from 1998. This chart indicates a steady increase in the total number of publications in this field.

2.2. Types of Green Roofs. Green gardens or roof gardens are divided into three main categories based on the executive system and depending on the average planting depth and the number of facilities required, namely, 1- extensive system, 2- intensive centralized system, and 3- modular system or planter box.

2.2.1. Extensive System. This system is also known as the low height or low thickness system. This type of green roof includes only one or two types of plants and a shallow growing environment [28, 29]. The term "green roof" is mostly applied to this class of roofs. Sedum is the most common plant that is used in this type of roof because it grows easily in harsh environments, has a low cost, and is relatively lightweight. However, other plants that are resistant to a wide range of weather and drought conditions and plants that contribute to biodiversity can also be used with this type of roof [30–34].

Due to the wider roof area, extensive roofs are light and thin structures that usually have a 6 to 20 cm deep growing medium. However, small roofs usually require heavier and thicker green roofs. The thickness of the growing medium ranges from 15 cm to 1 meters. Semicompact green roofs are a mixture of the two styles mentioned above, as their title indicates. They also have a thinner growing layer than a small roof but are thicker than a large roof, and the entire structure is 120 mm to 250 mm. The weight of the large roof is between 60 and 125 kg per square meter while the weight of the semi-dense roof is between 120 and 180 kg per square meter, and the weight of the compact roofs is greater than 180 kg per square meter and up to 500 kg per square meter. Compact roofs are the most expensive of the three systems, and wide roofs are the least expensive [16, 35–38]. Table 4 shows the advantages and limitations of this system.

2.2.2. Intensive Centralized System. Followed by aforementioned extensive systems, the intensive centralized system is the second class of green roofs. This type of green roof includes different kinds of plants and is designed similar to a park. This system often requires new structural requirements for the roof, especially for public access roofs [39–42]. For the centralized system, the term Roof Garden is mostly used. Plants used in this type of roof include shrubs, native and nonnative herbaceous plants, grass, and large tropical perennials [25].

Intensive green roofs could allow the growth of a wide variety of plants, such as trees and grass. In contrast, a small collection of drought-resistant plants, mostly with poor root systems, can usually only tolerate large green roofs. Most low-growing plants and grasses are viable options for wide roofs [23, 24]. Hence, wide roofs require less maintenance and do not require irrigation except in heat waves. On the other hand, intensive green roofs require a lot of maintenance and should be watered regularly [14, 26, 27]. Table 5 examines the advantages and limitations of this system. Furthermore, Table 6 compares intensive and extensive systems based on multiple factors.

2.2.3. Modular System or Planter Box. After the evolution of extensive and intensive systems, modular systems/planter boxes have emerged. In this framework, the plant and its planting medium are stored in special boxes covering most or all of the green roofs. The growing layer is continuous on the green roof within a nonmodular structure [16].

In Figure 3, the growing layer is a continuous sheet on the green roof within a nonmodular structure [8, 37]. No data were found regarding the limitations and advantages of a modular system in the literature background, and no more details could be provided accordingly.

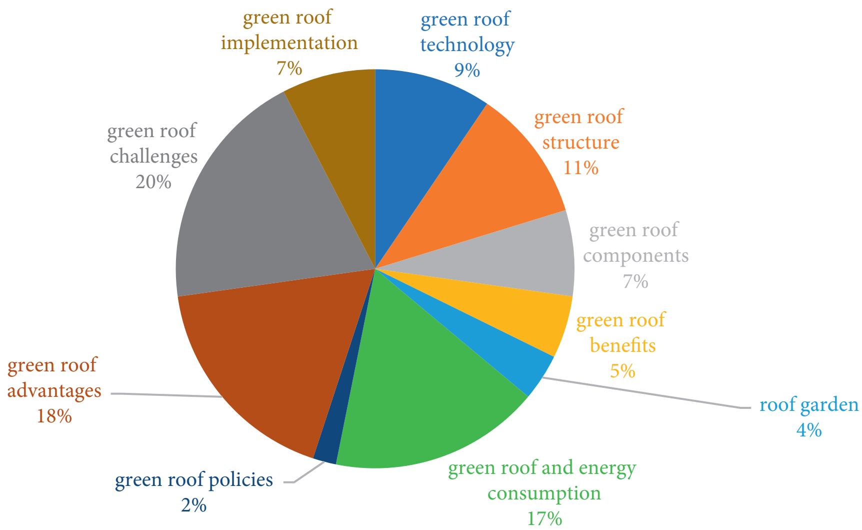

FIGURE 1: Keywords of some research were used in the current research in green roof.

TABLE 3: The number of articles and research in the field of the green roof by year of publication.

Year	#
1998	377
1999	333
2000	372
2001	426
2002	450
2003	519
2004	561
2005	651
2006	697
2007	837
2008	948
2009	1020
2010	1042
2011	1354
2012	1648
2013	1787
2014	2103
2015	2346
2016	2752
2017	3198
2018	3194
2019	3482
2020	3943
2021	1514

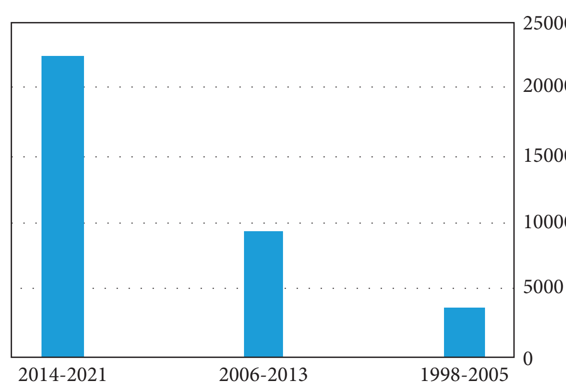

FIGURE 2: The number of articles and research on green roofs every seven years from 1998.

2.3. General Classification of Green Roof Components

2.3.1. Green Roof Structure. Creating different types of green roofs requires special planning and knowledge. Green roofs need technology beyond the usual roof engineering systems in terms of maintaining and controlling the weight of soil, rain, and snow and installing sidewalks [46]. A green roof consists of the following three parts [6, 47–49]:

(1) The roof of the building on which a layer of insulation such as gypsum or any other insulation is stretched, and sometimes it is mosaic, asphalt, or paving.

(2) A protective layer that separates the roof and waterproofing from the soil and plant layer.

(3) Soil, fertilizer, and garden irrigation system, each of which is carefully placed. Green roofs are designed to last more than 30 years. Hence, the materials used in constructing a green roof need to be replaced periodically. Generally, equipment manufacturers consider two scales for roof gardens: dense/compact roofs and wide roofs [47]. The application of each of these types depends on the definition of the use of the roof garden, the plant variety considered, and the amount of construction and maintenance budget [50]. Lightweight green roof systems require less maintenance and are more durable. Materials used can absorb rainwater and reduce the risk of flooding by slowing down the flow of water during sudden and torrential rains [51].

New roof garden irrigation methods minimize water consumption and maintain soil moisture to prevent rapid evaporation [52–54]. First, a layer of waterproofing and then a suitable drainage network is installed on the roof during

Table 4: Advantages and limitations of the extensive system.

Limitations	Advantages
Less energy saving and retention of water	Lightweight: normally, the roof does not need reinforcing
Extremely limited plant variety	Appropriate for spacious areas
Commonly, no links to recreation with other uses	Suitable for roofs with a 0–3 degree celsius slope
Unattractive to others, in fall in particular	Low upkeep and high durability
	No need for specialized irrigation and drainage systems
	The need for fewer technological skills
	Reasonable for retrofit projects as well
	Vegetation may grow on its own
	Relatively inexpensive
	More common
	Easier to request a planning reference for approval

Table 5: Advantages and limitations of intensive systems.

Limitations	Advantages
Heavier load on the building structure	Much more plant to produce and habitat diversity
Requires irrigation and drainage systems with resources, water, and materials	Properties of good insulation
Lower cost of capital and repairs	A park on the earth will simulate
More complicated processes and experience	Visually appealing
	Using a more varied range of ceilings for recreation
	Better quality of energy and capacity for water storage
	Longer lifespan on membranes

Table 6: The comparison between intensive and extensive systems.

Features	Intensive	Extensive	Source
Diversity	High	Low	[28, 43]
Maintenance	Complex	Easy	[28, 43, 44]
Cost	High	Low	[13, 28, 43, 45]
The thickness of growing media	>200 mm	<200 mm	[19, 28, 40, 43]
Construction	Complex	Easy	[28, 43]
Weight	>300 kg/m^2	50–150 kg/m^2	[28, 34, 43]

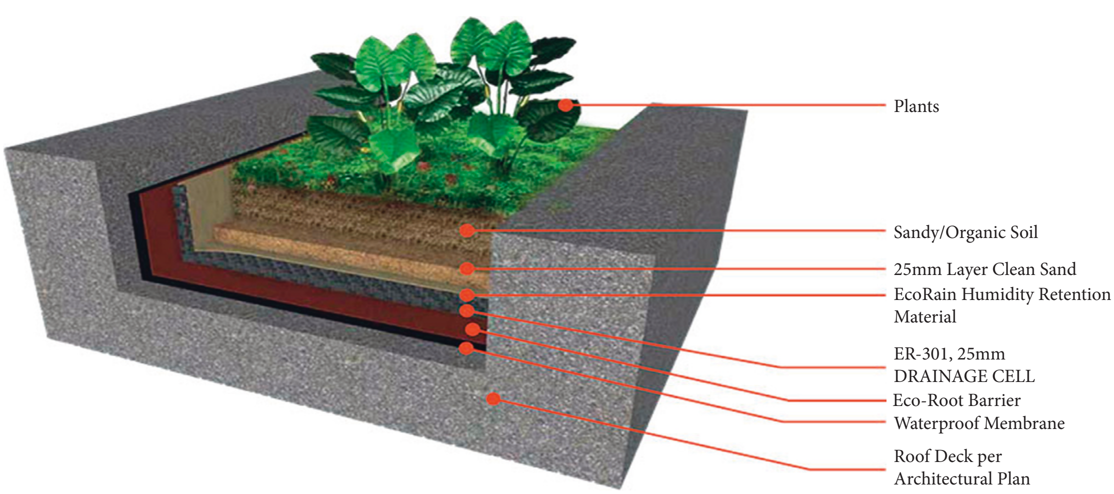

Figure 3: Green roof system [38].

construction. Creating the perfect growing environment is essential for green roof success. Unlike natural arable soil, this system is perfectly designed to fit the environment and does not become too heavy when wet. Eventually, the plants are planted. Cold and heat-resistant vegetation is used. Plants used for this purpose usually include herbaceous perennials, flowers, wild grasses, and mosses [29, 32–35].

2.3.2. Green Roof Components

(i) Plant layer:

While any plant could be planted mainly on the roof, barriers such as climate, building systems, maintenance costs, and ideas of green roof designers impact the final decision. As green roofs are built to be as light as possible, they also include plants that can grow in shallow soil [10, 19–21].

(ii) Growing medium:

The growing medium is the space in which plants begin to grow. Due to special structural requirements, the growing medium should have a lower weight than ordinary soil. In this case, the growing medium should be used as light as possible and weigh about 900 kg per cubic meter when it is wet. A typical mixture of one-third sand, one-third porous rock, and one-third artificial soil (a combination of rotten wood and vegetable manure) forms a suitable environment [23–25, 39–42].

(iii) Drainage layer:

Roofs usually hold a large amount of rainwater, which reduces the pressure imposed on the drainage system. However, there is always some excess water that must be drained. The drainage layer is applied between the growing medium and the protective layer for the rain and snow water to flow to the drainage system anywhere on the green roof [13, 55, 56]. The excess water can be disposed of in the following ways: 1- by the roof itself, 2- through gutters connected to slopes, and 3- waterways and water canals.

As a precaution, two outlet ducts or an outlet and a place for overflow should be installed. The outlets should be free of any plants, which is carried out by installing a valve on top of them for inspection. A terrace grid can be used in terraces [12].

The suitable drainage layer should be chosen based on the maximum water flow determined using precipitation details. The compressive strength, including its drainage layer, should be appropriate as it supports the plant and the growing medium [39–41]. A dense layer of extended soil is used for specific structures. But most green roofing companies use a corrugated plastic drainage mat with a structural pattern. The lowest possible drainage layer thickness is equivalent to standard 20 mm cardboard, but thicker mats will include an extra insulation layer [25, 39]. The drainage layer itself can be a complex collection of other layers.

(iv) Filter layer:

A filter between the growing medium and the drainage layer removes moisture from the root environment and prevents root rot. This filter can contain a fabric texture used in the non-woven system. Even modern geo-textile filters can usually be a layer of sand in one or two layers, which may be combined with the drainage layer [43].

(v) Root barrier:

It keeps the insulation and roof membrane from entering and destroying the roots. This layer is mostly used in the centralized system, placed under the final seal or waterproof thermal insulation or directly above it. This layer is generally made of a polyethylene shell and is often used in public projects where plants with strong and aggressive roots are grown and in which there is a lot of extra load [57–59].

(vi) Drainboard:

The top layer is filtered by a three-layer plate that extracts excess water from the roots. This layer serves as a defensive layer against the root as well. The middle layer, a conical cup, receives and retains excess water from the roots. Rainwater tends to minimize the rate of environmental emissions, causes air circulation, and avoids runoff from this layer. The bottom layer is a fabric filter that prevents damage to the membrane and insulation [30, 37].

(vii) Protection layer:

This layer includes coatings that protect the roof and insulation system from leakage and water penetration directly into the membrane. The protection layer covers the shield plate during operation. Based on the size and use of the green roof, this plate may be a strip of lightweight concrete, a sheet of solid insulation, a thick plastic sheet, a copper sheet, or a mixture of those. Most green roof structures do not generally need a shield and instead use a root barrier [17, 28, 60].

(viii) Roofing membrane or waterproofing layer:

This layer safeguards the roof against leakage and dripping. The membrane has been used both within an articulated waterproof layer and in the form of interconnected sheets. Selecting a proper membrane depends on the situation of the roof, price, and ease of installation and maintenance. In recent years, a product that combines a layer of root and membrane major barrier into one layer has been produced by some factories [17].

To avoid losing its effectiveness over time, a refining coefficient is entered in the calculations when calculating the required soil volume, which is carried out by adding a percentage of the soil.

3. The Benefits of Green Roofing

The quick urbanization and densification led to the reduction of green spaces. Sometimes, urban zones' natural resources and environmental values have been ignored. Among the suggestions to decrease the vitality loss in expansive cities, using adequately designed and implemented green rooftops with due regard to the natural environment is one of the most effective technologies [61]. Installing green roofs could aid in recovering the green areas in urban regions. Hence, green roofs can be viewed as an instance of environmental stewardship. It is usually implemented to depict environmental development activities and attempts that significantly guarantee perfect environmental resources necessary for current and next generations' lives. Green roof inventive plans are a collaborative attempt of the public and private sectors, including different stakeholders, like municipal managers, policy-makers, building designers, and builders, to improve the sustainability of cities [88]. In addition to their numerous benefits, green roofs can help reduce urban vitality loss, increase urban competitiveness, decorate the city, decrease urban pollution, and diminish urban pressures. It is possible to classify the contrast between green and traditional rooftops into two quantity and quality categories [61–63]. On green rooftops, the process of heat exchange is very distinct. Plants assimilate an incredible amount of sunshine through their natural processes, including photosynthesis, sweat, breath, and dissipation. When moving through to the roof of building materials, the rest of the sun's beams are converted into warm loads and affect the indoor conversation. Plants disappear and return water to the atmosphere, effectively regulating temperatures around them [16, 37].

Much research has been conducted to examine the benefits of green roofs in specific countries. Table 7 reports the number of studies in this field from 2006 to 2021 for twenty countries. Based on Table 7, about 40% of research has been conducted in Asia. Almost all of these studies conclude that green roofs are effective in reducing pollution and advancing the living environment, offering opportunities for inventiveness and improving social interactions [37, 50, 64].

Psychologists' research into the effects of flowers and plants on social behavior indicates that contact with nature and enjoying its beautiful scenery is an easy yet essential way to relax and soften the human spirit. Additionally, the calming effect that plants have on humans reduces society's psychological burden [63]. Besides, its comprehensive development of collective biological complexes can help reduce aggression, depression, and suicide and create spaces for human beings, especially the elderly, to relax and relieve themselves [50]. Some of the other benefits of green space can be listed as follows [37, 50, 61–66]:

Table 7: Green roof research by country from 2006 to 2021.

Country	#
China	10
Italy	6
Australia	4
Poland	4
Korea	4
Spain	3
Canada	2
Egypt	2
Japan	2
Iran	2
Taiwan	2
UK	2
Austria	1
Belgium	1
Chile	1
Colombia	1
France	1
Germany	1
Indonesia	1
Israel	1
Jordan	1
Lithuania	1
Malaysia	1
The Netherlands	1
Norway	1
Portugal	1
Saudi Arabia	1
Slovakia	1
Turkey	1
USA	1

(i) Adjustment to climate change: green space changes natural conditions and influences climate change.

(ii) Acting as a protective cover: green roofs cover and preserve the roof of the building while reducing the need for repairs. They prevent extreme temperature changes and fires due to grass and soil insulation layers by extending the roof's lifespan by shielding the building from natural or human-made destructive factors.

(iii) Providing wildlife habitat: green roofs contribute to the beauty of the residential unit and the surrounding area and give children happy and safe recreational spaces to play and older people to exercise.

(iv) Reducing the impact of urban heat islands: turning housing roofs into green spaces increases the exchange of air between high building density areas and free spaces between suburbs and the city center. This regulates the air temperature in the city center. In the city center, density increases the temperature and warms the air. The city center's air temperature is 2 to 3 degrees colder than in the suburbs.

(v) Improving the city's drainage system as a whole and balancing water levels outside the city.

(vi) The potential for sound insulation and thermal energy storage while minimizing energy consumption.

(vii) Roof gardens, especially in densely populated areas, help to improve air quality. In addition to absorbing dust, generating oxygen, and cooling the city during the hot summer months, plants, whether planted on the ground, on the walls, or on the roof of a house, will extend the green landscape and natural space.

Green roofs have several consequences for the city's ecology, the regional economy, and other facets of the urban climate. [37, 50, 64]. Overall, these effects can be summarized into the following six advantage groups:

(1) Soundproofing: in urban areas, streets are a big concern. Even though the façade covering helps reduce sound penetration, that is, reduce the amount of commotion from the outside to the inside of the house, the type of roof also impacts the overall noise pollution entering the house. Within the roof system, green rooftops maximize sound coverage. These rooftops diminish commotion by storing, reflecting, and transmitting sound waves. Soils and plants absorb and trap acoustic frequencies, which prevent their proliferation.

(2) Reducing heat effects: large cities rapidly absorb the sun's radiant heat and act as sources of heat emission due to their high levels of hard impermeability and lack of vegetation. The "urban heat island" phenomenon is one such condition. In this situation, there is a significant temperature difference between asphalt and bitumen-covered urban areas and vegetation-covered areas. Asphalt and concrete surfaces create a heat island. The ceilings and streets represent heat and light and establish a temperature bubble over the towns at dusk. However, according to research, the area's climate is influenced by the urban heat phenomenon, thus increasing the use of climate control and cooling equipment, which raises energy consumption, and the greenhouse gas phenomenon, which is the critical factor in ozone depletion. In terms of the region's surface energy and climate characteristics, a deeper understanding of the landscape and how the changes in the cover that are associated with urbanization happen over time can be very useful.

(3) Reducing air pollution: trees have a remarkable contribution in urban areas to decreasing the urban air toxic pollutants. By lowering the surface temperature, they decrease the photochemical responses of toxic pollutants such as ozone in the air.

(4) Reducing carbon dioxide: global warming is normally caused by the natural climate cycle. However, excessive use of fossil fuels has also contributed significantly to this phenomenon. Carbon dioxide is produced as a by-product of the combustion of fossil fuels. This compound prevents the infrared wave that is radiated back from Earth during a sunny day from leaving the atmosphere, which increases the average temperature. The vegetation on green rooftops absorbs carbon dioxide and reduces the overall temperature by allowing the radiation to leave the atmosphere in the absence of this compound.

(5) Reducing the load of sewage systems: green roofs decrease the flow of surface water, which improves the efficiency of the water flow and reduces the overflow of wastewater. Green roofs will carry 80–70 percent water in summer and 25–40 percent in winter. Eventually, water stored in the soil may evaporate or return to outer space. Furthermore, water flow is delayed due to soil saturation, which retains moisture and urban surface water, especially during seasonal rainfall, and storing it prevents runoff and overflow. Green roof vegetation can consume and remove more than 95 percent of cadmium, copper, lead, and 16 percent of "zinc" from the rainwater and significantly reduce nitrogen levels.

(6) Reducing heat transfer through building energy storage: during summer, green roofs help cool the roof space and keep it warm in winter by minimizing temperature fluctuations on the outside of the roof. In the winter, foliage reduces freezing, raising the roof's insulation.

Overall, the benefits of a green roof can be categorized into four classes as represented in Table 8.

3.1. Impact of Green Roofs on Climate Resilience Enhancement in Buildings. As a sustainable building element, the impact of green roofs is to improve the new and current buildings' resilience according to climate change conditions, energy demand, and indoor comfort. Despite the slightly increasing deterioration of indoor comfort conditions over time, it is noteworthy to mention that a green roof decreases the effects of external temperature fluctuations due to climate change. Green roofs are effective in improving the buildings' climate resilience. It should be noted that the impact made on indoor comfort is not the mere consequence of green roofs. Green roofs play a major role in mitigating the impact of urban heat islands and thus improving outdoor comfort condition. According to the relevant research background, such an impact depends considerably on the climatic region and the extent of the green roof dryness. This leads to a high and low level of mitigation, which is commonly achieved in the evenings and on cloudy winter days, respectively [67]. Nevertheless, while temperature mitigation may be still achieved at the rooftop level, such an effect on urban heat islands at the pedestrian level is minor in all climate conditions. In such a scenario, additional greening interventions such as planting trees and urban vegetation at the street level are considered a more effective mitigation strategy [68], which may be combined with an urban green roof deployment [69–71].

Table 8: Summary of the benefits of green roofs.

Class	Function
Ecological	Conservation of biodiversity, habitat creation and improving the ecological-biological quality of the city
Eclipse	Reducing the effect of heat islands and cold winds through thermal insulation
Environmental	Improving air quality by purifying airborne particles, exchanging oxygen and carbon dioxide, reducing noise through sound insulation, reducing the volume of rainwater runoff by preserving surface sewage, increasing water quality and preventing pollution, reducing the negative effects of electromagnetic radiation up to 99%
Economic and cultural	Reducing the cost of artificial ventilation, increasing the lifespan of roof insulation, increasing the value of the property, increasing the sense of belonging, saving energy by insulation in winter)

3.2. The Role of Green Roofs in Optimizing Energy Consumption. Green roofs reduce energy consumption for heating and cooling. Of the total solar radiation received by the green roof, 27% is reflected, the plant absorbs 60%, and 13% penetrates the soil [78–80, 101–105]. Studies have shown that green roofing can reduce the heat flow on the roof by 70% to 90% in summer and 10% to 30% in winter. This would also lead to a 75% decrease in the amount of energy consumption as well, because heat transfer is always from the body and space of the building [9, 17, 24, 28, 34, 81]. Therefore, the heat transfer from the roof is from inside to outside in winter and from outside to inside in summer. Still, this percentage varies according to the seasons and the amount of humidity. Green roofs reduce the cumulative electrical energy compared to the cumulative electrical energy consumed by conventional flat roofs during representative similar cooling demand periods. Therefore, extensive green roofs, especially with rubber crumbs as a drainage layer, can be a good tool for passive energy saving during summer in dry climates [82]:

(i) Heat transfer in summer:

Green roof layers help cool the roof space during the summer by reducing the heat fluctuations on the outer surface of the roof. They also increase the heat capacity of the roof by shading, moisture retention, and photosynthesis. The combination of soil reactions, photosynthetic reactions, and plant perspiration reduces the amount of solar energy absorbed by the roof layer. Green roof research suggests that most of the benefits of cooling in the summer are related to green roof sweating [9, 17, 20, 28, 48, 83, 84].

(ii) Heat transfer in winter:

In addition to increasing the heat capacity of the building by raising the roof layers, the green roof insulates the building against cold weather. It reduces energy consumption for heating the rooms by protecting the building with vegetation and soil and reducing wind speed [50, 77–79, 85, 86].

(iii) Roof insulation:

Plants continuously retain some air around their roots, which acts as a thermal insulation layer. The efficiency of this layer of thermal insulation in green roofs depends on the amount of moisture it retains. The higher the humidity of the roof, the lower its efficiency and the more heat it loses [47, 62, 81, 87].

(iv) Reducing the wind speed:

A study at the University of Toronto shows that green roofs in cold climates also have the necessary function to keep spaces warm. This study shows that the effect of green roofs in reducing the intensity of wind is greater than the effect of shading. Vegetation prevents the environment from freezing in winter, which increases the roof's insulation. It provides energy storage in winter [33, 36, 50, 78, 79, 85].

The temperature of flat roof and green roof spaces in winter shows that if the average daily temperature on a winter day is 0°C, the temperature of flat roof space is 0.2°C, and the temperature of green roof space is 4.7°C. This indicates that these roofs reduce heat transfer [9, 17, 24, 28, 34, 37, 48, 62, 83].

3.3. Green Roof and Economic Savings. The main portion of the roof has the role of a preservative wall that decreases the sun's direct radiation on the external wall, having a role in shadowing. This leads to the reduction of artificial ventilation expenses (cooling in summer) and an increase in property value. The environment temperature is disseminated vertically. Because of the perfect heat dissolution of the roof, the vertical air temperature does not alter considerably at night while it changes remarkably at noon. Because of suitable heat buffer, the front porch temperature is not too high, and as a result, the construction could be more efficient in the summer. Simultaneously, the roof equipped with shoulder eaves keeps the bamboo and wood elements safe against rainwater floods and extends the possible usage of building elements [91].

The cities of arid or semiarid zones may take advantage of preservative or no drainage and demand further water resources. Moreover, the evaporation forecast applications can complement precipitation forecasts to confine drainage while high evaporation demands are predicted. Cities do not have a similar number of flat roofs, and also, in some cities, the roofs do not have enough toughness to tolerate a blue layer to attenuate stormwater. It is necessary for roofs with adequate toughness to consider the extremes of future weather in their design by applying regional climate forecasts. Identifying the extremes of the upcoming weather could improve the decision process regarding the depth of

Table 9: Challenges and downsides of using green roofs.

Challenge	Main barriers
Budget	Compared to traditional roofs, the cost of building green roofs depends on the type, materials, climate, and the aesthetic decisions by customers Cheap electricity in some countries, which leads to the residents' unwillingness to install green roofs Lack of financial support from governmental or nongovernmental sources Different maintenance costs compared to traditional roofs Failure to provide public and private developers with financial facilities Lack of economically justified projects for developers from the public and private sectors Excess plant maintenance costs Lack of private-sector information on the benefits of investing in and supporting this sector
Managerial aspects and organizational policies	Nonconsideration of the green roof, along with other planning policies and urban green space architecture, as part of the sustainable green space scheme Failure to educate and inform municipality authorities, experts, and managers about the advantages of green roofs Lack of programs and technologies built-in municipalities and green space commissions to address the needs and challenges of green roofing Lack of symbolic public or private green roof projects Not using the successful experiences of other nations in this field Lack of consultants and contractors' persuasion concerning operations and researches Lack of local standards and a system for ongoing assessment to address challenges over time
Legal aspects	Lack of a legal basis for encouraging investment in this sector Lack of compulsory rules to build a green roof
Technical and scientific infrastructure aspects	Quick construction and fitting of ordinary roofs and easy access to their accessories and equipment Lack of awareness, practice, and relation with the green roofing industry Lack of the native green roofing contractors Lack of green roofing systems for residential houses, homes, etc. Lack of a robust framework of software and hardware to access information and equipment in the consultation and implementation phases The ability of traditional roofs to cover any type of building Lack of applied research for metropolitan areas to extend and justify green roofs and to assess different types of plant species Low scientific knowledge level for realistic evaluation in various local situations Inability to use mobile irrigation systems
Cultural aspects	Culturally normative compatibility with ordinary roofs Lack of participation and management space between individuals due to the growth and maintenance of green roofs in residential and commercial areas Lack of human capital and human staff preparation to construct, standardize and maintain green roofs Lack of nongovernmental bodies Lack of people's culture regarding the sensitivity and significance of environmental and climate issues and the need to improve the situation Lack of understanding of green roofs and their benefits by the public society
Geographical aspects	Lack of community awareness about green roofs and their benefits No green roofs in some metropolises or specific geographical areas within urban areas

the water preservation layer. Future research could explore factors that originated in the social and financial aspects of green roofs [43, 92–96].

3.4. The Performance of Green Roofs. The essential criteria to assess the performance of a green roof consist of aesthetic attraction, environmental contexts involving different types of climates, surface texture and depth, plant choice, methods of deployment, and preservation. The purpose of the design, easy deployment, and preservation asset allocation are the main criteria in specifying surface depth and plant choice that could affect aesthetics as well. Aesthetic goals should be considered before plant species selection since most species have their slumbering periods, such as native prairie grasses and perennials, in which the roof might not seem very "green" [90, 97–100].

Aesthetic attraction is more significant on small roofs developed for public services than on low-depth large roofs to manage stormwater. Some large roofs might not be easily seen from outside the building, and they could be viewed just from the air. Mixtures of evergreens and long-blooming flowering plants present a breathtaking sight while growing together. However, the dry weather of summer could change flowering perennials into a pile of browned-out, dead-looking flowers that might become a fire danger as well. Likewise, grass can be difficult to keep green during the summer, specifically on large roofs [75]. Irrigation is necessary and surface depths should be deeper to bring up perennial flowering herbaceous plants and grasses on large roofs. If proper irrigation is not accessible, tender species, like Sedum, Sempervivum, and Delosperma, are suitable selections due to their ability to resist long-term drought situations and other harmful environmental factors that often exist on a roof.

The aforementioned criteria are mostly subjective factors. As for mathematically objective measures, the three important physical parameters governing the green roofs' energy performance are as follows: 1- coverage ratio (σf), 2- leaf area index (LAI), and 3- foliage temperature (Tf). LAI provides information on the depth that the solar radiation has to go through before reaching the roof, indicating the level of its attenuation by the vegetation. The coverage ratio, σf, identifies parts of the roof that are directly hit by solar radiation, which is then characterized by a different energy model [70]. On the other hand, the foliage temperature, Tf, is clearly an important parameter of the vegetation's energy model and, in turn, of the green roof's energy model.

4. Challenges

There are many obstacles to designing green spaces, especially green roofs. Moreover, there are some drawbacks to using green roofs as well. First and foremost, the roof of the building needs to be reinforced in order to build a green roof. Also, most of these roofs are not intended for human presence. However, with alternative structures being planned and introduced, this defect can also be eliminated [44]. Reasonable structural requirements often include green roofs. Many existing roofs are not ideal for green roofs due to the extra weight that the soil and plants force upon the structure of the building [45]. For example, a concrete structure transforms into a green roof much more effectively than a wooden or metal structure.

The vegetation options for green roofs depend on the climatic conditions, the amount of shade, and the quality of the region's water to preserve vegetation for all seasons [72]. It should be noted that plants with deep roots can harm the roof water insulation performance and create problems due to the difficulty of repair [73–75]. Hence, experts should be consulted when choosing the vegetation of such gardens. Disregarding the impact of aesthetics, climate and microclimate could significantly affect plant preference. Notably, different levels of temperatures, sweltering and freezing temperatures, the levels of irradiance, wind speed, and the volume of rainfall during the year could specify which types of plants can be used in a specific region. The drought tolerance can be significant since high solar radiation levels and low media moisture could be typically the standard, specifically in large shallow systems [89].

Similarly, microclimates on the roof are affected by some parameters. Roof angle and direction might impact the power of the sun that reaches the building and surface moisture content. The nearby constructions might make the shadow a part of the roof, chimneys, and air-conditioning facilities might dry the surface, and industrial constructions' chemical smoke might affect the growth of the plant. Environmental contexts such as the volume of rainfall and temperature levels could limit the possibility of using specific types of plants or could necessitate irrigation. Though aesthetic attraction is a significant factor on many roofs, the selected plants should first have the ability to survive the harsh environment of the rooftop of an urban building [66].

Another downside of green roofs is their initial cost of implementation, which is higher than ordinary roofs. However, this expense is paid only once in the long run and is minimal due to the benefits above. To summarize, the overall challenges and downsides of green roofs are tabulated in Table 9 [45, 72–74, 76, 77].

5. Conclusion

Sustainable architecture is one of the new trends and approaches in architecture that many contemporary designers and architects have considered in recent years. This architecture, which is one of the solutions in the field of sustainable development and seeks to adapt to the environment, is one of the basic human needs in today's world. Creating green buildings aims to improve the climate, prevent the loss of energy used for cooling and heating, and prevent the harmful effects of construction on the environment. One of the most important technologies in sustainable architecture is the green roof, which, if properly implemented, will reduce energy loss and improve the aesthetics of the building. This technology aims at slowing down the growing trend of energy consumption, its adverse effects, and irreparable damage to the natural environment. If properly designed and implemented with climatic considerations in mind, a roof garden or green roof can significantly help reduce energy consumption. Creating greenery in the backyard space leads to the blocking of sunlight and reduces surface evaporation and transpiration. These changes have a positive effect on cooling the city's climate and the region and the indoor air of the building on which they are located. This cooling is done by reducing heat fluctuations on the roof's outer surface and increasing the roof's heat capacity. This keeps the space under the roof cool in the summer and regulates the temperature during the winter. Due to the improvement of social, economic, and environmental conditions, green roofs have been included in the planning of most developed cities in the world. This is promising, especially while heat loss through the roof is considered high in the nineteenth article of the national building and housing regulations regarding energy consumption. The green roof acts as a thermal insulator by increasing the roof layers and controlling the heat exchange between the inside and outside of the building. This study aimed to review the green roof and the issues of green and sustainable buildings and their advantages and challenges. Recent research on green roofing has grown significantly. Green roofs represent an increasingly important passive component in urban buildings due to the many benefits that can be attributed to them, such as reducing air pollution. For a future research project, we suggest that the obstacles to green roof implementation in developing countries be identified and ranked. Then, appropriate strategies can be adopted to address these challenges.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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