Potential Benefits of Application of Green Roofs on Buildings of Communist Period: Tirana Case Study

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Abstract

This research proposes the application of green roofs to the flat terraces of residential buildings, commercial buildings, and public-owned buildings in the city of Tirana. Green roofs have proven that they can offer ecological, innovative, and sustainable solutions. Application of green roofs provides multiple such as reduction of CO_2 in the atmosphere and on-site, management of rainwater runoff, reduction of noise pollution, addition of green areas, and reduction of urban heat air islands and brings a positive contribution to urban agriculture, recreation, flora, and fauna. Green roofs demand higher installation cost rather than conventional ones, but they prove to be more cost-effective and economical in the long run. As a case study, two buildings of the communist period built in one of the most urbanized areas of Tirana have been selected. The study examines the type of construction and the capacities that these buildings have to support different types of green roofs. Green roofs are classified according to the density of vegetation, applied technological solutions, and components used in construction. The long-term benefits of each roof type are compared with the cost of application, and based on the analysis, the most appropriate one is selected.

Keywords

Green roof · Intensive and extensive green roofs · Pollution reduction · Rainwater management · Sustainable design · Vegetation

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1 Introduction

Tirana is being built currently without the implementation of building codes, and it needs a lot of intervention and innovative ideas to make it a modern and efficient city. Tirana ranks as the most polluted city in Europe which at the end of 2020, scored 81.11 points in the air pollution index compiled by Numbeo (2020) agency. Consequently, the air quality is very low. Numerous problems are also encountered with rainwater management, lack of recreational and green spaces as well as effect of urban heat island by rising temperatures by 4–5 °C from reflecting built surfaces. Application of the green roofs over existing buildings could serve as a sustainable long-term solution, which can improve the quality of life. Although there are some sustainable and ecological projects in Tirana, their impact is still negligible in the improvement of the overall urban microclimate. The result would be more noticeable if the application of green roofs is done over the existing buildings.

Sustainable design seems to be the main focus in the field of long-term construction. The use of green roofs provide a sustainable solution which can resolve some of the urban problems. Green roofs are the upper surfaces of objects that are completely or partially covered with plants. Green roofs include various types of vegetation, starting from the low grass and plants to the shrubs, bushes, and even some trees (She & Pang, 2010). An important addition could be the possibility to use the green roof as vegetable garden. The rooftops occupy the considerable area of the city which is not used daily and does not contain any activity. These surfaces can be considered as a great opportunity for solving the vital problems of the city.

This research aims to find a sustainable and long-term solution for the green roofs taking into account the types of building structures and to provide a cost-benefit analysis for the selected roof types. The first stage of the research is related to the site selection and the analysis of its urban

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parameters. The site has been selected at one of the most urbanized areas of Tirana, and it is facing problems with the quality and the amount of public space, occasional flooding, and uncontrolled urbanization. The site analysis includes the identification of buildings with the greater potential for the application of the green roofs. The selection of the two buildings is based on their construction period, the footprint area, and the building height. From the central archive are taken all the drawings such as plans, sections, and facades of both buildings. The buildings have been 3D modeled, reproducing all the structural elements of the existing buildings, and the plans were redrawn. At the second stage, structural analysis of the buildings is carried out to find out the load-bearing capabilities of the flat roofs. Based on the load-bearing capacity, potentially applicable green roof systems have been introduced and cost analysis of their application has been performed. Vegetation analysis is based on the selection of the flora that is present in the district of Tirana. In addition, the cost analysis of required materials was performed based on the market prices. One of the priorities of this research is to find out more economically feasible and easily applicable urban-scale solution for the existing buildings. After the comparative analysis, the general evaluation of the benefits for each type of green roof is done through a comparative rating.

2 Classification of the Green Roofs and Major Benefits of Use

The basic components of a green roof are waterproof layer of the roof deck, root barrier, drainage membrane, filter layer or geotextile fabric, substrate or growing medium and vegetation (Allnutt et al., 2011). All of these layers have a primary function of protecting them from water, pests, and other organisms and also serve as very good insulators for protection against weathering and energy loss inside the building.

By the amount and type of vegetation green roofs are categorized into two main categories: intensive green roofs and extensive green roofs. Extensive roofs are suitable for the large areas, they are simple to design and install, don't require irrigation and the build-up height is 50–150 mm. Due to the lightweight, they do not require highly reinforced structures or special reinforcement systems. Also because of short vegetation and low weight it is possible to apply them even on the steep slopes. With build-up height of 150–1,500 mm, intensive roofs require highly durable structures since they can accommodate the wide range of plants and trees, combine hard and softscape, and create gardens, which are similar to the natural ones. Intensive roofs have costly start-up costs and require regular irrigation and maintenance, but they become more profitable after a long period of use and have good thermal insulation properties (Cath et al., 2007). Intensive green roof creates a load of 180–500 kg/m^2. Extensive green roofs are relatively light at 60–150 kg/m^2 (Cascone, 2019). The height of the roof is about 120–250 mm and the weight of 120–200 kg/m^2 (Raji et al., 2015). Extensive and semi-intense green roofs consist of almost the same materials due to the same typology they have. Since the semi-intense green roofs have higher weight and higher substrate level, the quality of the materials should be better and should have a longer lifespan. Also, the water capacity is higher and requires a proper drainage system to drain the water during storms in order to avoid the flooding of the roof. Extensive green roofs are the most popular types for the implementation due to the lower thickness of the roof layer, but the capacities of the intensive green roofs are higher in terms of the building energy balance, biodiversity, rainwater mitigation, and the urban heat island mitigation (Nguyen et al., 2022). Semi-intensive green roofs stand in-between of the two previous types. Reduction of the thickness of the green roof is the main challenge, but in the hot climate it may increase the overall temperature of the substrate and negatively affect the plants resistance (Savi et al., 2016).

Modular green roofs are systems that can be easily applied and in a very short time over a large area. The important layer for the modular system is the water isolation. Several types of insulators, such as bitumen or liquid insulators, can be used for this process. Green roof modular systems don't need the protection membrane from the plant roots and the water drainage layer, because the container or modular box performs this function. Modular systems don't require the filter layer since the drainage openings of modular boxes are positioned higher than the base of the box, and this creates the storage of moisture in the substrate and makes the plants more resistant during droughts. It also excludes the need for irrigation of planted vegetation. Built-up layer system consists of three or more layers. The main differences between the extensive green roof and semi-intensive green roof systems is the substrate layer and the water drainage system. Due to the construction properties, modular roofs have the big capacity in reduction of rainwater runoff (Korol & Shushunova, 2016).

Biodiverse green roofs are also known as brown roofs. The effects of construction and urbanization damage the biodiversity and habitat of many species, causing losses in the enrichment of biodiversity. Biodiverse roofs create living conditions for different species and attract insects such as bees which also help in the process of pollinating flowers (Hui & Chan, 2011). Blue-green roofs are a combination of green roofs and blue roofs and serve to store rainwater and make it usable for building purposes. These types of roofs reduce water consumption in buildings where they are applied, mitigate the heat island effect, and reduce electricity consumption in the building. Bio-solar green roofs include the photovoltaic panels installed over the green roofs. These types of roofs manage to produce clean energy and reduce the electricity consumption. Bio-solar green roofs are suitable mainly for the buildings with large area and loaded activity (Larsen et al., 2020).

Green roofs can provide multiple benefits, such as better rainwater management, air purification, enrichment of biodiversity, reduction of energy spends of building, reduction of urban heat island effect (Shafique et al., 2018). Green roofs offer a series of positive and beneficial effects on reducing temperatures during the summer in urban areas. Summer surface temperatures in the urban areas are on average 7–9 °C warmer, than in the surrounding rural areas, which have forest and vegetation cover. During the summer day, the temperature of the roof can rise to 50–90 °C (Arabi et al., 2015). The temperature of street surfaces and pavements is 27–50 °C hotter than the ambient air temperatures. However, surfaces that remain shaded or wet did not deviate far from the air temperatures (Berdahl & Bretz, 1997). The study conducted in Greece shows that green roof serve as good insulator to prevent the overheating. The indoor summer building temperatures are 0.6 °C cooler for the buildings with the green roofs, and the cooling loads are 11% reduced (Sfakianaki et al., 2009). Another study strengthens this case more by comparing black and green roofs. The green roof has the lowest heat loss rate and the black roof has the highest heat loss rate, and the difference between the black and green roofs is roughly 37% (Gaffin, 2010). Green roofs demonstrate the high ability in reduction of the fluctuations of the roof temperature during the summer time. The differences of the conventional roof daily temperature reach 20–48.5 °C, while for the green roof this parameter is just 5–11.3 °C (Maiolo et al., 2020). The comparative research on the thermal performance of the different types of green roofs conducted in Portugal shows that the extensive roofs have 2.8 times higher cooling energy demand than the semi-intensive roofs and 5.9 times higher than the intensive roof (Silva et al., 2016). Green roofs have greater contribution into the lowering of the energy balance of buildings with the lower number of floors, since the energy savings are the highest for the apartments, which are located directly under the roof. The cooling and heating loads can be 16% and 5% lower consequently with the implementation of the green roofs (Theodoridou et al., 2017). For the single-story building application the green roof causes 19% deduction of the annual energy consumption (Peñalvo-López et al., 2020). The implementation of the simple roof lawn in the conditions of Rome, Italy caused the 30% decrease of the heating demands and 51% of the cooling demands in comparison with the conventional roof (Evangelisti et al., 2020).

Another benefit, that green roofs provide for cities with the poor water drainage systems, is the management of rainwater runoff from building and the loading of the exhaust pipes. Annual reductions of runoff of green roofs with 8 cm deep media have been reported as 38–54% (Miller, 1998). A medium depth of 6.5 cm can retain 40% of the rain from a single 50 mm storm (Scholz-Barth, 2001). The capacity of water retention is limited by several factors, such as geographical position, the slope of the green roof, the thickness of the soil layer and its composition, the type of vegetation applied, and the surface area of the green roof. Palla et al. (2008) report that the green roof may be used as a medium to control the storm waters in Mediterranean climate with the average retain of the 85% of the water volume. Paço et al. (2019) propose to select the local drought-resisting plants and to combine the mosses and the vascular plants, which can use the retained water. The slope of the green roof directly affects the acceleration or deceleration of the water circulation, which accumulates in the drainage system. Vegetation type has an impact on the water retention capacity of the green roof since different plants increase the evaporation capacity of the collected water and slow down the flow of rainwater. The surface of the green roof affects due to the density and weight that rainwater causes, this increases the intensity of water circulation and reduces the water retention capacity. The secondary factors having the smaller impact on water retention are the type of materials used and the selection of the drainage system. According to a study conducted for different types of green roofs based on the thickness of their composition (5, 10, 20, 40, 60, and 80 cm), the average capacity of water retention ranges from 55 to 75% (Metselaar, 2012). For the 6-cm-thick extensive green roofs water retention can reach 30–57% (Neto et al., 2014), and for the semi-intensive green roofs with 20 cm thickness, it is about 85% (Palla et al., 2010), and for the extensive roofs from 39 to 43% (Wong & Jim, 2014). Despite on the fact, that intensive green roofs have thicker soil layer and denser and diverse vegetation than the semi-intensive roofs; the semi-intensive green roofs have better performance in managing rainwater, due to the large weight of water stored in the intensive green roofs.

Green roofs are used for the air purification. They can clean the air by lowering temperatures, removing pollutants directly from the air, and preventing additional air pollution (U.S. Environmental Protection Agency, 2018). A study conducted in Michigan and Maryland demonstrated that green roofs covered with low vegetation or sedum species with the height of 2.5–12.7 cm managed to sequestrate ~162 g of CO_2 per square meter (Getter et al., 2009). In Amman green roof demonstrated annual 3.68% reduction of the CO_2 emissions in comparison with the traditional one (Abdin et al., 2018). According to another study conducted on the effect, that green roofs have on environment, the results revealed that green roof system could induce up to 33.8% savings in terms of the combined cost reduction and environmental values (Li & Babcock, 2014). Green roofs demonstrate 84.71% less CO_2 emissions during their life cycle (Nadeeshani et al., 2021). Extensive green roofs have CO_2 payback time about 5.8–15.9 years (Kuronuma et al., 2018). Given the fact that the green roof layers contain polymers, in the long term the pollution caused during the production of components is balanced by the pollutants, which are gathered by plants (Bianchini & Hewage, 2012). Green roofs have a positive impact on increasing biodiversity and attracting the different species mainly in urban areas where the cities have deformed and displaced it. The sedums, herbs, grasses, or host plants create the habitat for the birds, butterflies, and insects. Green roofs may include the use of wood cavities, rocks, various types of substrates, sand, tiles, bricks, or nests for birds. In Mediterranean areas, the arbutus plants are more preferable than the sage plants since they can overcome better the drought climate (Raimondo et al., 2015).

The economic factor should be considered, because the green roofs have a higher initial cost than other roofs and require the periodical maintenance. If the public benefits are added into the assessment, the lifecycle cost of the green roofs can be retrieved in most of the markets (Feng & Kasun, 2018). The application of the appropriate modern technology is considered to be the main factor of economic green roof (Philippi, 2006). Application of the green roof can also increase the property value and gain more space for the residents. Green roofs extend the service life of the roof materials. With the increase of the green roof area, the cost of its application per square meter is decreased. For multifamily residential buildings with high number of floors, the share of costs can reach 0.4% of total construction costs of the building (Pfoser & Dierks, 2018). An experimental study from China demonstrates the overall ecological benefit of $3.37 per square meter of roof and the 10 years of the investments return (Cai et al., 2019).

3 Methodology of the Research

The study is organized in a several steps since it requires to perform the several analyses and to collect the data from different sources. At the first stage of the data collection, the following steps are done:

- Site selection in one of the most urbanized areas of Tirana, which has constant problems with the quality of space, growing density, pollution, and noise.
- The site analysis includes the identification of buildings with the flat roofs, which can be potentially converted into the green roofs.
- Selection of the two buildings of the most prevalent building typology in order to examine their load-bearing capacities.
- Redrawing of the plans, sections, and facades of the buildings based on the documents from the central archive.
- Modeling the 3D models includes all the structural properties of the existing buildings.

At the second stage, the structural analysis was performed including:

- Structural analysis of the buildings in order to find out the load-bearing capacities of the flat roofs.
- Comparison of potentially applicable green roof systems and cost analysis of their application.
- The analysis of the general benefits of green roofs has been carried out, referring to previous studies and articles.
- Vegetation analysis of plants, which typical for the Tirana region.
- Proposal of the new activities that green roofs can offer and evaluation of the potential social impact.

As the conclusion, this research aims to find more economically feasible and easily applicable green roof solution for the flat roofs of the existing buildings.

4 Analysis of the Case Studies

4.1 Selection of the Apartment Blocks

The site is located between the two main streets of Tirana, Kavaja Street and Durres Street and between the Skanderbeg Square and Reshit Petrela Street. The total area of it is 417,340 m^2. The site has been selected as one of the most urbanized areas of Tirana, which has problems, such as repeating flooding of the roads during the heavy rains, lack of greenery, high density, variety of the commercial activities, and lack of public recreational spaces.

The selected includes residential, commercial, educational, religious, cultural and governmental buildings. The higher buildings are located at the main streets. The buildings from communist period are constructed using the load-bearing brick walls, and the recent ones are built using the post and beam system. During the communist period, the urbanization was controlled and main blocks of residential buildings were constructed along the Durres Street, such as “Blloku Partizani” and “Blloku 21.” The satellite image elaborated using QGIS (Fig. 1) shows all the buildings which potentially can support a green roof. The buildings with pitched roofs and low-story buildings are excluded from the selection because of the low load-bearing capacity. The map is provided by the State Authority for GeoSpatial Information (ASIG) of Albania (ASIG, 2020). The functions of the selected buildings are mainly residential and office buildings. The total approximate area of buildings with flat roofs is 65,558 m^2 which is 16% of the total site area. The two buildings selected for analysis have the roof area greater than 500 m^2, a height of more than five floors and are built during the communist period. The building floor plans (Fig. 2) are extracted from the documents found in the State Archive of Construction (AQTN).

Case study 1 is the Partizani building, which belongs to a residential block located in front of State University of Civil Engineering. The Partizani building is a five-story residential building which was built using the brick retaining walls in 1968. It has a 515 m^2 footprint area. Case study 2 is the 12C building located at Adem Jashari Plazza. The building is a four-story residential building which was built using the brick retaining walls in 1958, and it has a 598 m^2 footprint area.

The slabs of the Case 1 are composed of horizontal beams, which support the weight and transfer it to the retaining walls. Analysis of ceilings was performed by analyzing each of the beams and applying it to the entire sole. The following section (Fig. 3) presents the typology of Partizani building slabs. The building has five types of slabs with the same structure and concrete grade, but with differences in the amount of reinforcement steel and slab proportions. Knowing the surfaces, the grade of concrete, the dimensions of the slabs, and the amount of iron, the maximum-resistant moment is found. Then the resistance moment of each slab is converted into a force. The ultimate load (UL) is needed to calculate the loads which have an impact on the structure: Dead Load (DL) = Concrete + Brick = 0.225*1.4, Live Load (LL) = 0.256*1.6

Fig. 1 Selected site and buildings which are suitable for the green roof installation (adopted by author from Google via QGIS)

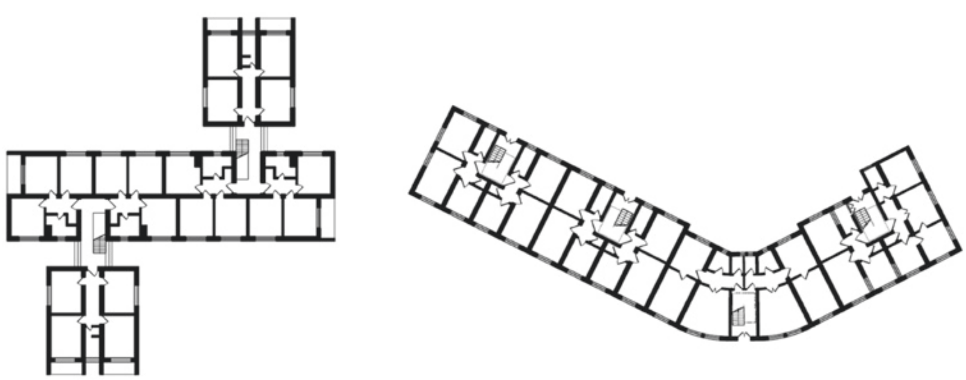

Fig. 2 Ground floor plan of Partizani Building (left) and Building 12C (right)

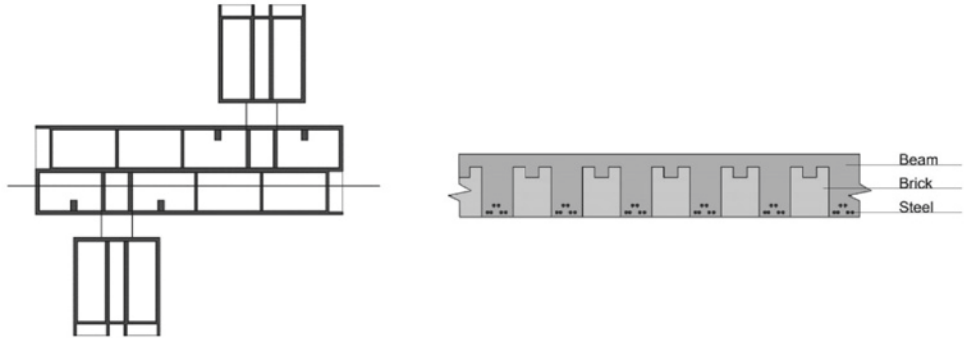

Fig. 3 Structural plan of Partizani building (left) and slab section (right)

Table 1 Structural plan of Partizani building

	Slab 1	Slab 2	Slab 3	Slab 4	Slab 5
Maximum resistant moment (KN)	3.26	3.70	1.99	1.52	0.75
Force (KN/m^2)	1.3	1.5	1.37	3.07	1.47
Allowed load (KN/m^2)	0.593	0.783	0.985	2.323	0.749
Permissible load (KN/m^2)	2.8	3.9	4.79	8.35	3.5
Maximum weight (KN/m^2)	2.1	2.9	3.6	6.25	2.6

from where the UL = DL + LL (1.4*0.225 + 1.6*0.256) = 0.717 kn/m. To find the allowable weight for meter on each beam is subtracted from the converted force F the ultimate load (F-UL) for each slab. Knowing the allowed load per square meter, the permissible load for each slab is found by multiplying the Allowed Load * Span Length * Number of the beams. Once the total permissible load for each slab is found, it can be converted into the permissible load per square meter for each slab by dividing the total permissible load of the slabs to the respective slab surfaces. From the permissible load is subtracted the tolerance of 25% of the total load-bearing capacity of the slab, which results in the maximum weight, that can be applied on each slab per square meter (Table 1).

The ceilings of the Case 2 building are built with the prefabricated soles. Due to the lack of data on the grade of concrete used for fabricated panels, a structural comparison with the Case 1 building is made. Figure 4 shows the structural plan of the building and the type of slab based on the drawings from the Central Construction Archive of Tirana.

The calculations are done for the slab with the largest area. Slab has a steel surface of 9,344.64 mm^2, which is divided by the area of the ceiling (9.6 m*3.65 m) to find the surface of the steel per square meter, which is 266.68 mm^2 per square meter. It's assumed that the slabs of the Case 2 building can support a weight greater than any of the slabs of the Case 1 building, due to the higher steel content. Referring to this data, it can be assumed that the slabs of the Case 2 can support any green roof that can be supported by the slabs of the Case 1 building.

4.2 Evaluation of the Supported Green Roof Types

For the application of green roofs, several important factors should be considered such as water insulation, thermal insulation, barrier for plant roots to prevent damage of the water insulation layer and layers to preserve moisture and minerals inside the soil to feed vegetation. Referring to the green roofs classification (Raji et al., 2015) (Table 2), the most suitable green roofs to be applied in the two analyzed cases are: modular green roofs, extensive green roofs, and semi-intensive green roofs. Intensive green roofs can't be applied in any of the cases, due to their heavy weight.

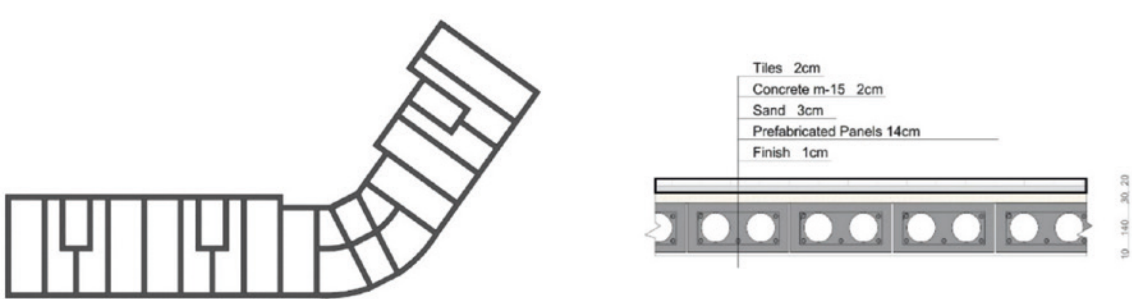

Fig. 4 Structural plan of 12C building (left) and slab section (right)

Modular green roofs, extensive and semi-intensive roofs do not require irrigation under normal conditions. In cases where the drought lasts too long and there is no rainfall, all types of the green roofs are recommended to be irrigated. Since modular and extensive green roofs have limitations in vegetation typology due to the dimensions that these roofs have, their need for the maintenance is minimal, while for the semi-intensive green roofs the maintenance should be periodic. The height of green roofs is different for each type. The lower roofs are modular with a height of up to 9 cm, the extensive roofs are up to 20 cm, and semi-intensive are up to 25 cm. Modular green roofs are lighter because they are constructed using a compact box, which is easy to install, with the average weight of 64.5 kg/m^2. Extensive green roofs are also lightweight structures due to their low vegetation and substrate ranging from 80 to 125 kg/m^2. The weight of the semi-intensive green roofs varies from 120 to 200 kg/m^2.

Each slab of Case 1 and Case 2 buildings can support modular, extensive, and semi-intensive green roofs loads, but they can't support the intensive green roof load excepting the slab 4 of the Case 1 (Table 3). Due to the lack of capacity of most of the slabs, the green roofs which could be applied on site are modular, extensive, and semi-intensive green roofs.

4.3 Green Roof Materials and Cost Estimation

The three types green roofs have the similar layers of waterproof membrane, substrate, and vegetation, but the root barrier, drainage membrane, and the filter layer of the extensive and semi-intensive roofs are replaced by the modular boxes for the case of modular roofs. One of the main goals of green roofs is to reduce the costs of flat roofs and increase their lifespan. One of the biggest dilemmas for the green roofs is the high cost of application due to the use of a range of materials. Referring to the prices of the domestic market in Albania and the international market, it is possible to get an approximate value for the total cost of materials for each typology of the green roofs (Table 4). Research shows that modular green roofs have a higher cost in the market, but their lifespan is longer, and in case of damages, the boxes are easily replaceable without intervention in the whole structure of the roof.

4.4 Suggested Vegetation

The climate of Tirana is classified as a humid subtropical climate according to the Köppen classification. Based on the classification of the climate zones in Albania, Tirana is located in the field Mediterranean area. The summer months are hot and moderately humid/dry, while the winter months are cool and humid. The annual temperature is 14.8 °C in average, while the hottest month is August, when the temperature reaches 24.7 °C and the coolest month is January with 5.2 °C. The maximum precipitation occurs in November with 150 mm, while July scores as the driest month with just 33 mm of rainfalls (Climate-Data.org, 2022). Tirana ranks 8th among major European cities with the most sundials. It has a high level of solar radiation with ~2,400–2,600 h of sunshine per year (AEA, 2014). The city is located in the 9a Plant Hardiness Zone (Teqja et al., 2017), which can be characterized by a long summer season providing the long period for vegetation growing. The

Table 2 Classification of green roofs

Green roof types	Modular	Extensive (built-up)	Semi-intensive	Intensive
Irrigation	No	No	No	Regular
Maintenance	Minimal	Minimal	Periodic	Regular
Weight (kg/m^2)	64.5	60–150	120–200	180–500
Build-up height (mm)	60–90	60–200	120–250	150–1,500

Table 3 Supported roof types

	Case 1 Partizani building					Case 2 12C building		
	Slab 1	Slab 2	Slab 3	Slab 4	Slab 5	Slab 1	Slab 2	Slab 3
Modular	✓	✓	✓	✓	✓	✓	✓	✓
Extensive (built-up)	✓	✓	✓	✓	✓	✓	✓	✓
Semi-intensive	✓	✓	✓	✓	✓	✓	✓	✓
Intensive	✗	✗	✗	✓	✗	✗	✗	✗

Table 4 Green roof materials and estimated costs

	Modular (Lek/m²)	Extensive (Lek/m²)	Semi-intensive (Lek/m²)
Waterproof membrane	320	320	320
Modular boxes	3,600	–	–
Root barrier	–	950	950
Drainage membrane	–	–	640
Filter layer	–	230	230
Substrate	150	150	280
Vegetation	30	30	1,800
Total material cost	3,300	2,320	4,220
Labor cost	400	1,200	1,200
Total cost	3,700	2,520	5,420

temperatures below zero are exceptional for Tirana climate, and the cultivated plants, such as vegetables, citrus and fruit trees, herbs and blossoming shrubs should be heat-tolerant. Green roofs of the Mediterranean area have low thickness, high usability, don't need the specific maintenance and may contribute to the passive cooling of the buildings. Tirana, although with a very urbanized urban center and lack of greenery, has suburbs rich in vegetation. To select local plants, that are applicable for the green roofs, the classification is based on their maximum height and on the lifespan. There should be used the types of plants, which provide a continuous surface and permanent greenery. Often the application plants require the maintenance, irrigation, and cutting. In general, the vegetation applied on modular green roofs and extensive green roofs should have a low height and require as little care as possible. It's more adequate to have plants with small roots resistant to drought and rapid growth spread. The most commonly used vegetation on modular and extensive green roofs belongs to the succulents family, as sedum, which has high resistance to drought. Sedums also minimize the water loss, which helps to increase the water retention of green roofs. There are selected the plants, which have an average length of less than 30 cm and a lifespan of more than 3 years. The local plants, that can potentially be applied to green roofs in Tirana, are *Thymus vulgaris*, *Teucrium polium*, *Trifolium pretense*, Coltsfoot, *Thymus serpyllum*, Oregano, Red Zorba Oregano, *Plantago major*, *Chamaemelum nobile*. A mix of succulents, such as sedum, requires less water, can resist in the difficult conditions of the open roof surface. CAM plants minimize water loss, helping with storm water management, while also offering the benefits of evapotranspiration (evaporating water from a plant by absorbing it through the roots and emitting it back out through the leaves as vapor) (Vegetal, 2013).

5 Discussion

One of the main benefits of green roofs is the delaying runoff peak of rainwater inflows and the reduction of the volume of rainwater discharge in the drainage system. The decrease in the volume of discharge occurs due to the ability of the vegetation layer and the soil to maintain a significant percentage amount of water, depending on the climatic factors and to restore it to the atmosphere through the evaporation phenomenon. This facilitates the central water discharge system as it significantly reduces the amount of water deposited in them during heavy rainfall. Both case study buildings have low-slope roofs of 3–5 degrees, so the water circulation coefficient is lower than in high-slope roofs, this slows down water flow and increases the capacity of water retention. Tirana's climatic conditions favor the application of semi-intensive green roofs, because Tirana has heavy and frequent rainfalls. The composition of green roof using the dense and diverse vegetation increases the capacity of evaporation of rainwater and reduces its flow in the drainage system.

Green roofs have high efficiency because the green layer exposed to sunlight enhances the evaporation process which brings a softening of temperatures, which in conjunction with the process of photosynthesis of vegetation absorbs energy from sunlight. The green roofs act as a cooling system by absorbing air energy and lowering temperatures. As the capacity of the green roof for water retention increases, so does the evaporation process, which results in a greater cooling efficiency. Green roofs, in addition to the positive impact they have on reducing the UHI effect on an urban scale, also play an important role in maintaining of the indoor temperature in the buildings. They serve as thermal insulation layer, contributing into the lowering of the temperatures during the summer and increasing during the winter. The massive application of the green roofs creates a local microclimatic zone, which reduces the use of energy for heating and cooling and increases the lifespan of the roof itself by protecting the materials from the sunrays.

Modular green roofs in contrast to built-in extensive green roofs, have higher moisture content, due to modular boxes which create a water collection at the bottom. The presence of water at the bottom of these boxes prolongs the process and amount of evaporation. The common geotextile layer below the soil layer serves for the longest possible storage of moisture. Semi-intense green roofs composed of a thicker layer of soil and a higher vegetation, which increase the water retention capacity, provides better shading effect, and gives the higher contribution into the process of air purification. The application of semi-intensive green roof gives better results for mitigating the urban heat island.

Fig. 5 Potential use of the green roof as cafeteria, meeting place, place for the social activities, resting area, or the herbs garden

Plants have the ability to improve air quality by absorbing pollutants or carbon dioxide and releasing oxygen. The impact that green roofs have on improving air circulation is related to the two main constituent layers of green vegetation and soil. Green roofs have an indirect impact on reducing pollution as they reduce the need for energy use. However, it is difficult to give accurate results in terms of evaluating the effects that green roofs can bring on air improvement. The impact of green roofs applied on a large global scale brings efficient results in improving the air and carbon sequestration. The measured PM10 concentration in Tirana was 124–127 $\mu g/m^3$, which is well above the EU limit value of 40 $\mu g/m^3$. Application of green roofs in the selected site may increase the air purification by 17%.

Green roofs may increase activity and liveliness on the terraces of residential buildings (Fig. 5). They give potential solutions for increasing communication of the residents and for improving the social life. Green roofs can be considered as a compensation to reclaim the ground space occupied by the buildings. Their application at the city scale can create a new ecological vision of the city. Green roofs offer opportunities to create playgrounds, adding space dedicated to children, and improving the social quality of the city. Their application should be done using all safety measures such as setting restrictive barriers, equipping with lighting at night, and placing retaining balustrades. Green roofs could be transformed into the cafés and restaurants and also can be used for family or social gatherings since of the most frequent activities of the citizens of Tirana is the consumption of coffee. They can serve as a place to organize small community performances, local meetings, political meetings, announcements, conversations. Semi-intensive green roofs can be planted with medicinal or aromatic plants that serve for daily use as spices in the kitchen, or teas with curative properties. Since Tirana is one of the sunniest cities in Europe, green roofs can be used for the sunbathing. Green roofs can also be used as relaxation spaces to spend free time, listen to music, read books, and meditate.

Despite on the all potential benefits, the application of the green roofs in Tirana currently is in not very common. The existing roofs are mainly the private initiatives, rather than the t result of the common policy. The green roofs can be used by the residents of the house, but they are not opened for the public. The roofs are equipped in a very simple way with the planting pots and boxes, which can be managed easily by the community (Fig. 6). In addition, the residents installed the benches and pergolas which make the place more comfortable. The roofs are also used as place for the solar water heaters, antennas, water tanks, and photovoltaic panels, which belong to the residents of the last floors. The green roofs in Tirana were widely used during the COVID-19 pandemic, when the residents were not allowed to get out of their homes, and therefore, they spend the time at the roof terraces. Currently, the demand is lower since the social life came closer to the pre-pandemic level and the citizens prefer to stay at the outdoor cafeterias and enjoy the music, social atmosphere, and food and drink services, which are provided there.

6 Conclusion

The evaluation of all three types of green roofs is done taking into account all the benefits they have. The result of the evaluation (Table 5) shows that application of semi-intensive green roof in our cases is more efficient and brings more benefits in a long term than other roofs that can be applied in these two cases.

Fig. 6. Existing green roofs in Tirana

Table 5 Green roofs performance (✓—poor, ✓✓—medium, ✓✓✓—good)

	Modular	Extensive	Semi-intensive
Cost of materials	✓✓	✓✓✓	✓
Cost of application	✓✓✓	✓✓	✓
Air pollution filtration	✓✓	✓	✓✓✓
Water retention	✓✓	✓	✓✓✓
Biodiversity	✓	✓	✓✓✓
Heat island reduction	✓✓	✓✓	✓✓✓
Recreational spaces	✓	✓✓	✓✓✓

Semi-intensive green roof gives better benefits in reducing of the level of pollution, has a greater capacity of water retention, is more efficient in terms of biodiversity, and has better capacities in reducing the UHI effect, but has higher material and application costs. Modular green roof has very good performance since it has a short installation time and good performance in water retention capacity, but poor performance in attracting the biodiversity and limitations for the organization of the recreational spaces. The extensive green roof has cheaper materials, but the benefits of modular and semi-intensive green roofs are higher.

The examined case studies show that residential buildings of the communist period have the ability to support three out of four main systems of green roofs, such as modular, extensive, and semi-intensive green roofs. Starting from the economic analysis, costs of the materials and the cost of the application, the total costs for each of green roof systems are estimated. The three selected systems of green roofs contribute positively in reduction of energy consumption for heating and cooling, in managements of the water flow, in extension of the roof lifespan. Lowering the level of pollution, lowering temperatures during the summer which further affects onto the local climate change, increase of green spaces, social, cultural, and lifestyle improvements are the features that make green roofs an efficient solution. One of the most important benefits is the displacement of the activities to the terraces of buildings, and this would make the city more diverse and more aesthetically pleasant.

References

Abdin, A., El Deeb, K., & Al-Abbasi, S. (2018). Effect of green roof design on energy saving in existing residential buildings under semi-arid mediterranean climate (Amman as a case study). *Journal of Engineering Sciences, 46*(6), 738–753. https://dx.doi.org/10.21608/jesaun.2018.115008

AEA, (2014). Sustainable energy for Albania. Tirana: AEA Albania Energy Association.

Allnutt, P., Bussey, W., Gedge, D., Harris, M., Henning, I., Poë, S., & Zeller, S. (2011, October 20). *The GRO green roof code*. Groundwork Sheffield. Permagard.

Arabi, R., Shahidan, M. F., Kamal, M., Ja Afar, M. F., & Rakhshandehroo, M. (2015). Mitigating urban heat island through green roofs. *Current World Environment, 10*, 918–927. https://doi.org/10.12944/CWE.10.Special-Issue1.111

ASIG. (2020, October 21). State authority for GeoSpatial information. *ASIG*. https://geoportal.asig.gov.al/map/?auto=true

Berdahl, P., & Bretz, S. E. (1997). Preliminary survey of the solar reflectance of cool roofing materials. *Energy and Buildings, 25*(2), 149–158. https://doi.org/10.1016/S0378-7788(96)01004-3

Bianchini, F., & Hewage, K. (2012). How green are the green roofs? Lifecycle analysis of green roof materials. *Building and Environment, 48*, 57–65. https://doi.org/10.1016/j.buildenv.2011.08.019

Cai, L., Feng, X-P., Yu, J-Y., Xiang, Q-C., & Rui Chen, R. (2019). Reduction in carbon dioxide emission and energy savings obtained by using a green roof. *Aerosol and Air Quality Research, 19*, 2432–2445. https://doi.org/10.4209/aaqr.2019.09.0455

Cascone, S. (2019). Green roof design: State of the art on technology and materials. *Sustainability, 11*, 3020. https://doi.org/10.3390/su11113020

Cath, H., Coombes, B., Carwardine, H., & Butcher, K. (2007). *Green Roofs*. Chartered Institution of Building Services Engineers.

Climate-Data.org. (2022, July 4). Titana climate (Albania). Climate Data. https://en.climate-data.org/europe/albania/tirana/tirana-714992/

Evangelisti, L., Guattari, C., Grazieschi, G., Roncone, M., & Asdrubali, F. (2020). On the energy performance of an innovative green roof in the mediterranean climate. *Energies, 13*, 5163. https://doi.org/10.3390/en13195163

Feng, H., & Kasun, H. N. (2018). Economic benefits and costs of green roofs. In G. Pérez, & K. Perini (Eds.), *Nature based strategies for urban and building sustainability* (pp. 307–318). Elsevier. https://doi.org/10.1016/B978-0-12-812150-4.00028-8

Gaffin, S.R.-P. (2010). *A temperature and seasonal energy analysis of green, white, and black roofs*. Columbia University.

Getter, K., Rowe, B., Robertson, P., Cregg, B., & Andresen, J. (2009). Carbon sequestration potential of extensive green roofs. *Environmental Science and Technology, 43*, 7564–7570. https://doi.org/10.1021/es901539x

Hui, S., & Chan, K. (2011). Biodiversity assessment of green roofs for green building design. In *Proceedings of joint symposium 2011: Integrated building design in the new era of sustainability* (pp. 10.1–10.8). Hong Kong: ASHRAE-HKC/CIBSE-HKB/HKIE-BSD.

Korol, E., & Shushunova, N. (2016). Benefits of a modular green roof technology. *Procedia Engineering, 161*, 1820–1826. https://doi.org/10.1016/j.proeng.2016.08.673

Kuronuma, T., Watanabe, H., Ishihara, T., Kou, D., Toushima, K., Ando, M., & Shindo, S. (2018). CO_2 payoff of extensive green roofs with different vegetation species. *Sustainability, 10*, 2256. https://doi.org/10.3390/su10072256

Larsen, T., Maurer, M., & Leitao, J. (2020, October 20). *Multi-functional green roofs*. Eawag Aquatic Research. https://www.eawag.ch/en/department/sww/projects/multi-functional-green-roofs/

Li, Y., & Babcock, R. (2014). Green roofs against pollution and climate change. A review. *Agronomy for Sustainable Development, 34*, 695–705. https://doi.org/10.1007/s13593-014-0230-9

Maiolo, M., Pirouz, B., Bruno, R., Palermo, S. A., Arcuri, N., & Piro, P. (2020). The role of the extensive green roofs on decreasing building energy consumption in the mediterranean climate. *Sustainability, 12*, 359. https://doi.org/10.3390/su12010359

Metselaar, K. (2012). Water retention and evapotranspiration of green roofs and possible natural vegetation types. *Resources, Conservation and Recycling, 64*, 49–55. https://doi.org/10.1016/j.resconrec.2011.12.009

Miller, C. (1998). Vegetated roof covers, a new method for controlling runoff in urbanized areas. In *Proceedings from the 1998 Pennsylvania stormwater management symposium.* Villanova: Villanova University.

Nadeeshani, M., Ramachandra, T., Gunatilake, S., & Zainudeen, N. (2021). Carbon footprint of green roofing: A case study from Sri Lankan construction industry. *Sustainability, 13*, 6745. https://doi.org/10.3390/su13126745

Neto, P. D., Mendiondo, E. M., & Ohnuma, A. A. (2014). Análise da Retenção Hídrica em Telhados Verdes a Partir da Eficiência do Coeficiente de Escoamento. *Revista Brasileira De Recursos Hídricos, 19*, 41–52. https://doi.org/10.21168/rbrh.v19n2.p41-52

Nguyen, C., Muttil, N., Tariq, M., & Ng, A. (2022). Quantifying the benefits and ecosystem services provided by green roofs: A review. *Water: An open access journal*, *14*(1), 1–37. https://doi.org/10.3390/w14010068

Numbeo. (2020, October 20). Pollution in Tirana, Albania. *Numbeo*. https://www.numbeo.com/pollution/in/Tirana

Paço, T., de Carvalho, R., Arsénio, P., & Martins, D. (2019). Green roof design techniques to improve water use under mediterranean conditions. *Urban Science, 3,* 14. https://doi.org/10.3390/urbansci3010014

Palla, A., Gnecco, I., & Lanza, L. G. (2010). Hydrologic restoration in the urban environment using green roofs. *Water, 2*, 140–154. https://doi.org/10.3390/w2020140

Palla, A., Lanza, L., & Barbera, P. (2008). A green roof experimental site in the Mediterranean climate. In *11th international conference on urban drainage, Edinburgh, UK*

Peñalvo-López, E., Cárcel-Carrasco, J., Alfonso-Solar, D., Valencia-Salazar, I., & Hurtado-Pérez, E. (2020). Study of the improvement on energy efficiency for a building in the mediterranean area by the installation of a green roof system. *Energies, 13*, 1246. https://doi.org/10.3390/en13051246

Pfoser, N., & Dierks, F. (2018). *Green roof guidelines for planning*. Ministry of Environment and Energy (BUE).

Philippi P. M. (2006). How to get cost reduction in green roof construction. In *Fourth annual greening rooftops for sustainable communities conference, awards and trade show, Boston*.

Raji, B., Tenpierik, M. J., & Dobbelsteen, A. (2015). The impact of greening systems on building energy performance: A literature review. *Renewable and Sustainable Energy Reviews, 45*, 610–623. https://doi.org/10.1016/j.rser.2015.02.011

Raimondo, F., Trifilò, P., Lo Gullo, M., Andri, S., Savi, T., & Nardini, A. (2015). Plant performance on mediterranean green roofs: Interaction of species-specific hydraulic strategies and substrate water relations. *AoB Plants, 7*. https://doi.org/10.1093/aobpla/plv007

Savi, T., Dal Borgo, A., Love, V., Andri, S., Tretiach, M., & Nardini, A. (2016). Drought versus heat: What's the major constraint on Mediterranean green roof plants? *Science of the Total Environment, 566*(56), 753–760. https://doi.org/10.1016/j.scitotenv.2016.05.100

Scholz-Barth, K. (2001). Green roofs: Stormwater management from the top down. *Environmental Design Construction*, *4*, 63–69.

Sfakianaki, A., Pagalou, E., Pavlou, K., Santamouris, M., & Assimakopoulos, M. (2009). Theoretical and experimental analysis of the thermal behaviour of a green roof system installed in two residential buildings in Athens, Greece. *International Journal of Energy Research, 33*, 1059–1069. https://doi.org/10.1002/er.1535

Shafique, M., Reeho, K., & Rafiq, M. (2018). Green roof benefits, opportunities and challenges—A review. *Renewable and Sustainable Energy Reviews, 90*, 757–773. https://doi.org/10.1016/j.rser.2018.04.006

She, N., & Pang, J. (2010). Physically based green roof model. *Journal of Hudrologic Engineering, 15*, 458–464. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000138

Silva, C., Gomes, G., & Silva, M. (2016). Green roofs energy performance in Mediterranean climate. *Energy and Buildings, 116*, 318–325. https://doi.org/10.1016/j.enbuild.2016.01.012

Teqja, Z., Kopali, A., Libohova, Z., & Owens, P. (2017). A study of the impacts of climate change scenarios on the plant hardiness zones of Albania. *Journal of Applied Meteorology and Climatology, 56*(3), 615–631. https://doi.org/10.1175/JAMC-D-16-0108.1

Theodoridou, I., Karteris, M., Mallinis, G., Tsiros, E., & Karteris, A. (2017). Assessing the benefits from retrofitting green roofs in mediterranean, using environmental modelling, GIS and very high spatial resolution remote sensing data: The example of Thessaloniki, Greece. *Procedia Environmental Sciences, 38*, 530–537. https://doi.org/10.1016/j.proenv.2017.03.117

U.S. Environmental Protection Agency. (2018). *Estimating the environmental effects of green roofs: A case study in Kansas City, Missouri*. EPA.

Vegetal I. D. (2013). *Green roof design guide*. Vegetal.

Wong, G. K., & Jim, C. (2014). Quantitative hydrologic performance of extensive green roof under humid-tropical rainfall regime. *Ecological Engineering, 70*, 366–378. https://doi.org/10.1016/j.ecoleng.2014.06.025