[Proceedings of the Fábos Conference on Landscape and Greenway Planning](https://scholarworks.umass.edu/fabos)

Volume 7
Issue 1 *Moving towards Health and Resilience in the public realm*

Article 62

August 2022

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Recommended Citation

Farkas, Dóra; Kisvarga, Szilvia; Orlóci, László; Neményi, András; Boronkay, Gábor; Honfi, Péter; and Kohut, Ildikó (2022) "An overview of the typical plant application possibilities of green roofs in Hungary," *Proceedings of the Fábos Conference on Landscape and Greenway Planning*: Vol. 7: Iss. 1, Article 62.
DOI: https://doi.org/10.7275/dwzb-5636
Available at: https://scholarworks.umass.edu/fabos/vol7/iss1/62

An overview of the typical plant application possibilities of green roofs in Hungary

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1. Abstract

Green roofs play a key role in the sustainable development of cities, and creating and increasing green spaces seems to be the most effective solution. Extreme conditions in cities are not conducive to plants. The key issue is the suitability of the species that can be used for this purpose. Due to their wide tolerance and toughness, *Sedum* species are most commonly used for extensive green roofs. They have a smaller biological product, but with their associated plant surface they are able to provide the expected ecological service even in a particularly thin medium. The performance of green roofs varies depending on the type of vegetation. Studies show that many other perennials are potentially more beneficial than the *Sedum* species. Of course, these also require more maintenance. Greater use of grasses in roof gardens can have a number of benefits. Grasses, on the other hand, are relatively undemanding, they can be used even in extensive conditions, their heavy metal and drought tolerance is outstanding, and they can withstand the harsh conditions of cities. The deeper medium required by the trees is only available in intense roof garden conditions. Thanks to the grass breeding in Hungary, Hungary has a huge genetic background, which can provide an excellent starting point for the selection of a specifically roof garden variety. In order to have a more efficient, economical and sustainable future, it is important to study and research the plants we use and to expand our knowledge. Thanks to the grassland breeding in Hungary, it has a huge genetic background. This summary will help you review the options, goals, and guidelines for finding the plant species needed for roof gardening.

Keywords: green roofs, climate change, sustainable, *Sedum*, grasses

2. The changing climate

The phenomenon of urbanization, or urbanization, is increasingly characterizing our society (Zhao et al., 2017). As a result of congestion, town houses are also built on top of each other, and the continuous expansion of buildings and the large extent of concrete surfaces drastically reduces the proportion of green areas (Prekuta and Gerzson, 1998). This leads to the development of an urban heat island effect (Mohajerani et al. 2017). Climate projections suggest that global warming and the increasing frequency of extreme weather events will further exacerbate urban heat waves (de Munck et al., 2018). As the process of urbanization is not projected to reverse and the majority of the world’s population will live in cities, effective solutions to the problem of heat stress are needed (Zhao et al., 2017).

Despite the innovations, the more important principles and practices of green roof construction have been retained, and engineering design has been modified only in terms of quality and variety (Jim, 2017). Green roofs can place a considerable weight on buildings, which is why lightening them is a very important task. Often, due to the poor roof structure of buildings, the thickness of the planting medium is not ideal either, as the amount of load can be influenced most by the thickness of the planting medium. However, it is also necessary to keep in mind to maximize the efficiency of the green roof, to provide plant habitat (Aguiar et al., 2019).

The role of green roofs is extremely important for innovative stormwater treatment measures aimed at partial restoration of natural conditions (Viola et al., 2017). Cities are often built on floodplains, are created as a result of deforestation (Guzzetti et al., 2005), or water does not reach the soil due to a significant increase in the number of areas covered with concrete (Houston et al., 2011).

3. Benefits of green roofs

Of the strategies already developed, creating, increasing, and expanding green spaces seems to be the most effective solution (de Munck et al., 2018), in reducing the urban heat island effect (Szuróczki and Tőkei, 1988), and roof gardening can be an innovative and effective way to mitigate the environmental impacts of urbanization, combined with providing many important ecosystem services (Rocha et al. al., 2021).

Green roofs have several benefits, such as improving the heat management of buildings as well as reducing energy demand (de Munck et al., 2018). They are most effective at the peak of the growing season (Dobi et al., 2013). This can play a key role in the sustainable development of cities in the 21st century and can provide significant benefits and better living conditions for future generations (Mata et al., 2020). They provide a number of benefits for the environment, the economy and the urban landscape. They help balance a variety of environmental loads, including balancing and mitigating heat, strong winds, scorching sun, and freezing cold (Fan and Wang, 2011). They reduce the impact of the urban heat island effect, are able to trap dust and carbon and retain particles, and purify the air (de Carvalho et al., 2020). They improve the heat management of buildings and, as a result, reduce the energy consumption of homes (de Munck et al., 2018). It has been recognized that with the current pace of urbanization, the continuous abandonment of the countryside could lead to the extinction of many plant species. The use of these species on urban green roofs may not only save endangered stocks (Mata et al., 2020) but also bring back the connection of urban citizens with nature (Köhler and Kaiser, 2021). In addition to the adverse environmental impacts of urbanization, green roofs help alleviate negative social and economic burdens (Aguiar et al., 2019).

Water supply has always been, and still is, a major problem for mankind (Domokos, 1934; 1964). In areas with hot, subtropical, desert climates, the ecological services provided by roof gardens are demonstrably less effective. In hot areas, water is an even greater treasure during drier periods, so increasing green spaces is often not a solution. However, we should not forget about the other advantageous aspects of green roofs, which may still make it worthwhile to install these gardens (Andric et al., 2020). In order to solve the heat and water shortage, irrigated green areas in the form of flower beds and garden lawns planted with native Hungarian plants have been present in Hungary since the 1930s. There has always been a strong emphasis on the research, application and breeding of species suitable for such purposes (Domokos, 1934; 1964).

Green roofs can effectively provide ecosystem services through evapotranspiration and nutrient cycling, which depend on, among other things, plant species, substrate type, and depth (Dusza et al., 2017). The leveling of the stock, the size of the foliage surfaces and the presence of water surfaces that cool in summer and heat their environment in winter are extremely important. Even very small water surfaces have a significant climate-modifying effect (Dobi et al., 2013). Preferably, the depth of the substrate (Dusza et al., 2017) rather than its composition has a greater influence on the coexistence of associations (Vasl et al., 2019). Interactions between substrate type and depth, in turn, strongly influence ecosystem functions (Drusza et al., 2017). The type of root system of the planted plants also plays a major role in this, as they change the physical characteristics of the soil (Rocha et al., 2021). Artificially produced substrate blends have been developed, typically from pumice and zeolite, to have ideal physical properties (Carlos et al., 2020). However, their disadvantage is that, compared to natural soils, the transpiration value of favorably formulated artificial media was lower and the dissolved organic matter was leached out more intensively (Dusza et al., 2017). The depth of the medium has a great influence on the retention of precipitation, although the amount of water retained is highly dependent on the climate (Viola et al., 2017) as well as on the mainly widely tolerated native taxa installed in the roof garden. In the long run, they are able to change the structure of the medium with their roots and thus increase its water-absorbing capacity (Carlos et al., 2020). This ability typically ranges from a less efficient, extensively maintained, narrower crop layer to a more receptive, intensively maintained, thicker substrate (Viola et al., 2017). Current models of climate change predict an increase in extremism. This means that there is a growing demand for green roofs with lower water consumption (de Carvalho et al., 2020).

4. Applicability of plants, possibilities on green roofs

In an urban environment, roof gardens are installed in ecologically sensitive areas, where plants have to withstand harsh conditions (Aguiar et al., 2019) that are not typical of their optimal living conditions and are therefore not accustomed to such extremes (Carlos et al., 2020). Due to the urban anthropogenic impact, biodiversity has been drastically reduced, the remaining habitats have become completely fragmented and degraded (Fahrig, 2003), and the levels of carbon dioxide, dust and heavy metals are well above average (Hao et al., 2000). Pollution caused by heavy metals is not good for plants. For example, copper is required in small amounts but is toxic in large quantities to ornamental plants, limiting the spread of grasslands and herbaceous flowering plants (Gladkov et al., 2020). Due to the large concrete surfaces, the temperature is very high. The combination of strong winds and the freezing cold that replaces heat in winter prevents plants from developing normally on roof gardens (Fan and Wang, 2011). In addition to the harsh climatic conditions, many species must be accustomed to the artificially created environment. The medium is often not thick enough, due to the load-bearing capacity of the slab, high solar radiation and low water replenishment, or sometimes prolonged water cover, and the associated nutrient leaching, also pose difficulties for plants (Aguiar et al., 2019).

Although plants for green roofs should be selected based on their typology, morphology, and garden climatic conditions (Zanin and Bortolini, 2020), vegetation with very little water demand is often considered (de Carvalho et al., 2020). In the case of extensive planting, the vegetation layer is mainly prepared for drought-tolerant grasslands, low-growth rock garden plants and steppe vegetation. These usually do not require regular maintenance, except during the planting period (Koppány, 1994). Examples include drought-tolerant mosses that have the potential to complement or even replace commonly used species, increasing the sustainability of lower water use in green roofs (de Carvalho et al., 2020).

But often monocultures of only *Sedum* species are used on extensive green roofs (Zanin and Bortolini, 2020). *Sedum* species, that survive even in extensive conditions, have a smaller biological product, but with their associated plant surface they are able to provide the expected ecological service even in thin media (Prekuta and Gerzson, 1998). Compared to other species, *Sedum* proved to be a very hardy genus. It is highly productive even on substrates thinner than 10 cm, with excellent tolerance to extreme climates, sudden temperature fluctuations, scorching sun, strong winds, and even poor soil nutrient content (Tuttolomondo et al., 2018). Such *Sedum*-based roof garden solutions are able to survive even in dry periods (Köhler and Kaiser, 2021). Its success is ensured by its excellent vegetative propagation tendency and the ability of the plant to cover the ground. It is constantly renewing itself, spreading incredibly fast, allowing the area to cover quickly, and be able to retain moisture in the substrate, creating a kind of microclimate on the surface (Tuttolomondo et al., 2018).

While xerophyton *Sedum* species that do not require irrigation in drier climates are more advantageous for planting, it should not be overlooked that the performance of green roofs varies depending on the type of vegetation (Rocha et al., 2021). However, the use of larger plants also requires changes in the depth and nutrient content of the substrate (Köhler and Kaiser, 2021). Irrigation may then be necessary to make the roof garden intense and to match similarly designed, ground-floor gardens (Prekuta and Gerzson, 1998). Due to the presence of a deeper medium, more precipitation seeps into the soil and is able to be stored there for a longer period of time. Higher nutrient levels promote biomass development and increase CO2 uptake. Due to the more diverse plant association, a unique microclimate can be created, which increases the efficiency of the roof garden, increasing evapotranspiration (Köhler and Kaiser, 2021). There are also many new opportunities in plant applications. By planting trees, we can achieve a more balanced climate in the city, as it does not allow the environment to warm up during the day and the air does not cool down so much during the night (Báthoryné et al., 2021). The rain does not come directly to the surface either, but the canopy of the trees catches the falling rain, so the water only gradually reaches the ground, thus extending the time of water replenishment. This allows it to evaporate for a longer period of time, cooling the air and increasing its humidity (Szuróczki and Tőkei, 1988). However, due to the old, weak slabs typical of cities, the establishment of intensive roof gardens is only possible in limited quantities. Green roofs that require extensive maintenance are playing a greater role (Aguiar et al., 2019).

The flower is a major aesthetic and environmental element of the urban ecosystem (Gladkov et al., 2020). In addition to their ornamental value, herbaceous perennials and semi-woody flowering plants have a higher water retention value, potentially more advantageous than *Sedum* species (Zanin and Bortolini, 2020). In the case of hybrids of *Ageratum* and *Petunia*, it was observed that although less frequent watering periods reduced the growth vigor of the plants, they developed as well under the influence of water that was rarely irrigated but enriched with nutrients as often irrigated individuals. This is not true for all taxa, and for *Mentha spicata*, nutrient replenishment did not improve plant vegetative growth (Elansary, 2017). It is also possible to use herbaceous, shade-tolerant plants when planting roof gardens. By covering the medium, they contribute to the efficiency of roof gardens and increase the activity of other plants. They offer an excellent opportunity to improve the biodiversity of roof gardens (Aguiar et al., 2019). Herbaceous plants have already been bred to tolerate urban heavy metal pollution. *Agrostis stolonifera* and *Chrysanthemum carinatum* species showed a tendency to adapt to copper (Gladkov et al., 2020).

5. Sustainable opportunities in Hungary

Although there are many new opportunities for plant application when using intensively maintained roof gardens, the plants develop properly only due to the abundant water and nutrient supply. Without maintenance, the plants will die (Koppány, 1994). Grasses are present all over the world, dominating the flora even in the harshest conditions (Oakes, 1990). These taxa are mostly an association of bushy grasses, dicotyledonous plants that are highly sustainable under extensive conditions (Szendrői, 2003). They are able to provide a wide range of ecosystem services, from animal feed to the remediation of a polluted environment (phytoremediation) and phytotherapy, contributing to biodiversity and the nutrient cycle. They play a role in protecting the soil and improving fertility (Abaye, 2019), not to mention the excellent heavy metal tolerance of grasses (Gladkov et al., 2020). In addition to their many functions, they can be divided into several groups according to their needs, based on their tolerance, regenerative, cracking ability, drought or shade tolerance (Szendrői, 2003). Smaller-growing or stunted species are very often found in hot, dry areas due to tolerance of greater water scarcity. They are able to survive longer periods of drought by embarking on intensive seed production (Oakes, 1990). This is how the so-called "dry grasslands" are created, where the spontaneous vegetation can survive without care and be reborn every year (Koppány, 1994). Some taxa protect against water scarcity by creating drastically reduced leaf area or folding their leaves during droughts, greatly reducing transpiration, while others survive by developing their roots, penetrating deeper (Oakes, 1990).

When grasslands are used, the environment cools faster during the night, producing cold air in the city. However, it heats up faster during the day (Báthoryné, 2021). Thin turf bricks can be used to green old, light-duty roofs because they are light and can be maintained in extensive conditions (Koppány, 1994). The solution to today's growing water shortage may be the use of domestic ornamental grasses in green farming (like *Festuca* or *Bromus* species), which can better withstand the increasingly extreme climates of the Pannonian Basin climate, while also providing adequate ornamental value (Kováts, 1961). Thicker vegetation solutions have generally been used in greening solutions common in northern Europe. Precipitation and moisture are much higher in these areas than in Hungary (Koppány, 1994). In Hungary, most of the grasses used as ornamentals have been bred and grown in Western Europe, often enjoying a wetter, more continental oceanic climate (Kisvarga et al., 2019). In Central Europe, the weather conditions are slightly more unfavorable for green roofs. The climate is drier and the temperature fluctuates more (Koppány, 1994), which can cause difficulties even during extensive maintenance (Kisvarga et al., 2019). However, by using and combining mainly native species, the problem can be eliminated, as they are well adapted to warm and dry Mediterranean summers (Rocha et al., 2021). Thanks to the breeding work of Zoltán Kováts, Hungarian varieties bred from native species, such as Bromus erectus 'Budapest', Festuca heterophylla 'Liget' and Festuca sulcata 'F112', can be used excellently for greening cities (Kisvarga et al., 2019). In Hungary, the breeding of ornamental grasses has been practiced since the 1950s. Initially, about 50 grass species and 250 varieties were collected at the beginning of breeding and then subjected to drought and shade tolerance experiments in sandy areas with reduced nutrient content. The result of many years of work has become several state-registered ornamental grasses (Kováts, 1961).

6. Conclusion

Ever since the birth of ancient cities, humankind has been preoccupied with the question of how to bring nature back into its life. The negative consequences of global warming, climate change and the development of urban heat islands are once again highlighting the issue. Due to the finite number of urban areas, the use of roof gardens is now being put into practice. Globally, green roofs are being installed in more and more places. There is a lot of research on breeding plants that can be planted in such conditions to improve the efficiency of the ecological service they provide. The often extreme conditions in the cities are not favorable for the plants. Due to the high temperature fluctuation, the increased concentration of pollutants, the constant scorching sun and the prolonged drought, taxa installed in roof gardens have to meet serious challenges. However, due to the old, weak slabs typical of cities, the establishment of intensive roof gardens is only possible in limited quantities. Green roofs, which require extensive maintenance, will play a greater role. The commonly used *Sedum* species are the most popular choice today, and in most cases these plants are planted. But studies show that the productivity of many other herbaceous perennials is similarly good, if not better, on green roofs. In many cases, its ornamental value also surpasses the spectacle provided by *Sedum* taxa.

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