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Extensive Green Roof Study on a Retrofit Building in Berlin, Germany: Report After 34 Years of Monitoring

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ABSTRACT

This report describes the continued observation of the plant development on a green roof on a retrofit building in Berlin from 1986 to 2019. These ten extensive green roofs with a total area of 655 m² have different exposures and slopes. This project symbolizes a shift in the urban planning paradigm in post-war Berlin away from demolishing blocks of the housing that survived World War II to gradual renovation of the remaining historic rented courtyard buildings. Over the same period, the understanding of cities as ecosystems has grown. That means that concepts relating to local energy generation, waste management, and new modes of traffic as well as more greenery were key elements in the design. Green roofs were an essential means of adding vegetation to the urban scape. The systematic study included a full neighborhood block. A smaller part of the block was realized and financed as a case study. These extensive roofs were one of the first installations on sloped roofs with pre-produced turf mats in Germany. In total, 124 vascular plants were found over the 34 years of observation. Only five species from the original turf mat community were present all years and dominant for the entire period. The other five, *Festuca rubra*, *Dactylis glomerata*, *Lolium perenne*, *Poa pratensis*, *Plantago major* disappeared after a few years. All roofs of this building complex were given the same fabric-reinforced turf mats. This was a pioneer green roof technology at the time for sloped roofs in Germany. The main findings were that the species richness is not related either to the area or the slope of the roofs. Significantly better growth performance is related to environmental factors, especially in wet or humid conditions compared to dry years. The roof turf mats represent a stable vegetative cover over all the

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years. Such types of extensive roofs, cultivated on pre-produced turf mats, provide reliable protection against erosion that require little maintenance. In 1984 such mats were pioneering roof technology, and the long-term observations confirm the quality of this type of construction, making this project a role model for retrofit projects in North America as well.

Key words: *extensive green roofs, long-time-observation, pitched roofs, Berlin*

INTRODUCTION

This project is not the first modern extensive green roof (MEG)of Berlin, but it was the first based on an ecosystem study for a whole Berlin city block. The team headed by Martin Küenzlen collected data about abiotic, biotic, and social facts for Block 108 in Berlin-Kreuzberg to pioneer a green multi-criterial concept for an inner-city block (Autorenkolletiv 1981). This neighborhood with its rental tenements typical for Berlin dates from the early period of industrialization at the start of the 20th century and was in great need of renovation by the 1980s.

The interesting feature of these typical Berlin blocks dating from around 1900 in relation to urban planning was that they were characterized by social mixture of inhabitants with more imposing apartments on the street fronts and much smaller apartments in the courtyard areas. These blocks also rent shops to small businesses. This is a role model for a diverse inner-city mixture with a high urban density. The typical four-story buildings had eaves of 22 m, which was the limit set by fire safety regulations. The attics were not used, because the weak U value of 1.42 W/(m²·K) was an energy challenge not just in winter but also in hot summers. However, this rooftop area had the potential for quality living spaces—especially if extra insulation is combined with green roofs. Green roofs were known and sometimes used in Berlin as extra insulation as well as a fire protection method (Rüber 1860).

This project is an ecological example for a compact city with additional living space in the rooftop area. The International Building Exhibition in Berlin from 1979 to 1984 (Liepe et al. 2010) was the framework used to improve and to establish such visionary concepts. On this basis, and financed as a study by the German Federal Ministry of Interior (there was no ministry specifically for environmental issues at that time) in cooperation with the State of Berlin, it became possible to realize the concept as a demonstration project. Monitoring was part of this concept. This is the stage where the author became involved as part of the research team led by Prof. Reinhard Bornkamm.

Research questions related to green roofs that were explored in this project were: Are green roofs possible on steep roofs up to 45° inclination? Is it possible to avoid erosion by using pre-produced turf mats? This was one of the first green roof projects in which this technology, including a special seed mixture, was tested. How long do these large-scale green roofs last? The relevance of this project for the North American market is that multi-story retrofits with green roofs is a growing market in many projects.

The green roofs were included in the annual monitoring conducted by the author from the planning phase up to 2019 (Figure 1). Preliminary reports for the first years are printed in Koehler and Schmidt 1988; Koehler 2007; Koehler and Poll 2010). In these sources, the aim and selected methods are described in detail. This paper will be the final report of this project.

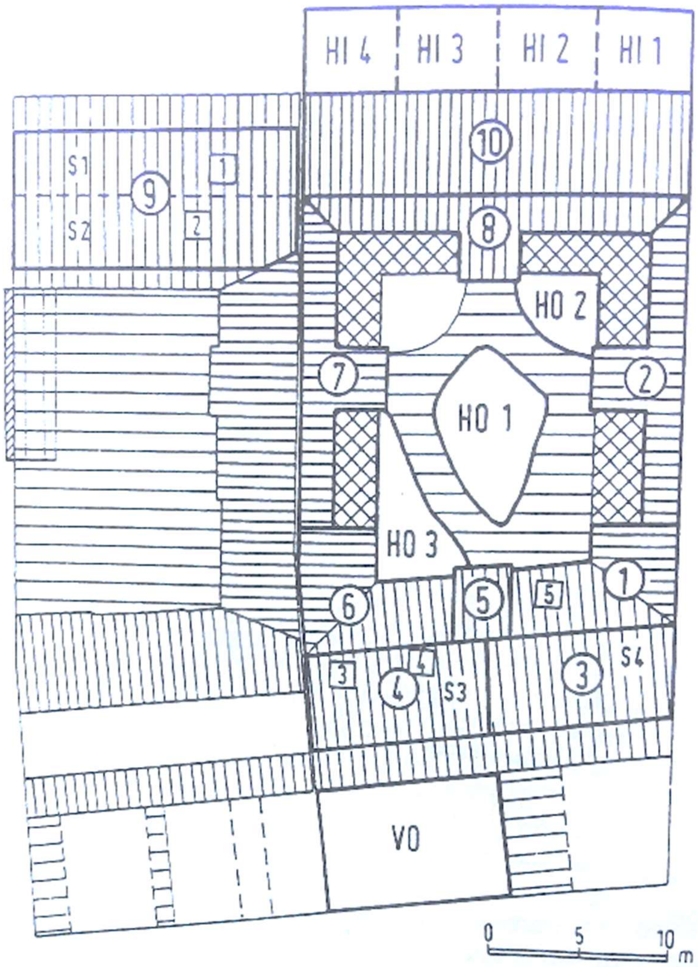

Figure 1. The numbers in the circles represent the 10 roofs with different slopes. The numbers in the squares are the plots for test seeds without turf mats in the first project stage between 1986 and 1988. These plots were covered completely after a few years by the surrounding roof vegetation. Source: Koehler and Schmidt 1997.

Roof Construction

The roofs have an insulation layer of Styrofoam under the timber construction. The sloped roofs included integrated thrust thresholds against erosion (Figure 2). Because of the inclination of all roof parts, an additional drainage layer is not used. The single layer of 10 cm growing media is a mixture of expanded clay, sand, and humus. At time of installation in 1985, the soil had: a usable field capacity of 15.4 liter/m² (in 10 cm); a pH value of 7.6; total carbon of 3.9%; total nitrogen of 0.1%; lead content of 202 ppm; cadmium content of 0.34 ppm, and copper content of 19.4 ppm. There were less changes since the second improvement in 2009 (Koehler and Poll 2010). The vegetation layer is a pre-produced reinforced mat containing a mixture primarily of the following plants: *Dactylis glomerata,* *Poa pratensis, Koeleria pyramidata, Lolium perenne, Festuca rubra, Poa compressa, Allium schoenoprasum*, and *Sedum acre.*

a

b

c

d

Figure 2a–d. Details of the green roof installation in September 1985. Upper row: Scaffolding and lifting the older roof to construct the roof level apartments. Lower row: Installation of the thrust-thresholds and the PVC layer. Lower right: With the final turf mat layer.

The turf mats had a vegetation coverage value of about 84% in the first year. The green roofs had no irrigation installed. But the residents in the back building understand, that irrigation has a double benefit for cooling their rooms and to support the vegetation. This irrigation only worked in the first two years, as long as this tenant lived there.

RESEARCH METHODS

Each year in May/June, a full plant observation was performed by recording the cover value in percentage ground cover of each plant species on the sub roofs separately (Table 1). The values for *Allium* as an indicator plant were recorded separately. Also observed were some data related to plant height and phenology information as well as special features, such as any erosion and the need for maintenance.

Weather data were analyzed on the date of the annual data collection. The information was summarized by identifying as dry or wet vegetation season until the data collection started in June. This is intended to interpret plant cover and species composition relative to weather data. Over this period, 18 years were classified as wet and 16 years as dry, there were significant differences in the cover values, species and cover of *Allium* related to these defined weather conditions (Table 3). The vegetation is well adapted to the local climate conditions throughout this time. The annual data sets were prepared in Excel including the presented graphs. For statistical tests, SPSS, version 27, was used.

Table 1. Characteristics of the 10 green roofs and some species numbers.

Roof number	Inclination in /slope°	Exposure	Size in m^2	Total # of vascular plants in 34 years	Ave. species per year	Ave. cover in % vascular	Cover in % of *Allium*
1	2–3	Flat	42	56	15	94	65
2	45	West	54	49	13	87	53
3	10	North	61	55	14	91	56
4	10	North	61	56	15	91	58
5	30	North	15	48	15	93	54
6	2–3	East	46	59	15	91	59
7	45	East	48	45	14	80	29
8	30–45	South	110	51	15	86	36
9	2–3	Flat	110	54	18	83	49
10	45	North	110	44	14	92	42
Total green roof size			655 m^2	Total number of vascular plant species			124

RESULTS

The following interpretation was based on the ten roofs. The intention to also monitor several plots without any vegetation mats was only successful for the first years. After only a few years, all areas are settled initially by annuals, such as *Bromus tectorum*, and after a few more years they resembled the typical turf mats around them, dominated by *Allium schoenoprasum* and *Festuca ovina*.

There was almost no maintenance required, apart from replanting on the ridge, and no tree seedlings were found on the roof mats. A remarkable feature for the entire observation period is the domination of *Allium schoenoprasum*. The value for this species is therefore highlighted here. On Roof 9 there were also some lichens from the genus *Cladonia*, particularly *Cladonia rei*, discovered across on average of 5% ground cover since the year 1994 onwards. This is due to the poor growing media and the improving environmental conditions in the city center of Berlin. About 100 km north of this roof, on the green roofs of the Neubrandenburg University of Applied Sciences, *Cladonia rei* can cover up to 50% coverage on comparable roof substrates. The reason lies in the emission load of the metropolitan area (own measurements).

Species richness and size of the roofs

All data are presented for the 10 roofs over 34 years (Figure 3). The trend line shows that size is not a relevant factor for a higher number of plant species. This result is due to the use of the green roof mats, which completely covered an area of more than 80% from the start. Therefore, there was only very limited space for additional introduced plant species. In this project, the primary goal was to have full vegetative cover to prevent erosion. This was achieved for all main parts of the roofs. The only difficult area was the ridgeline of Roof 7. Some *Sedum* plantings here solved this problem in the first years.

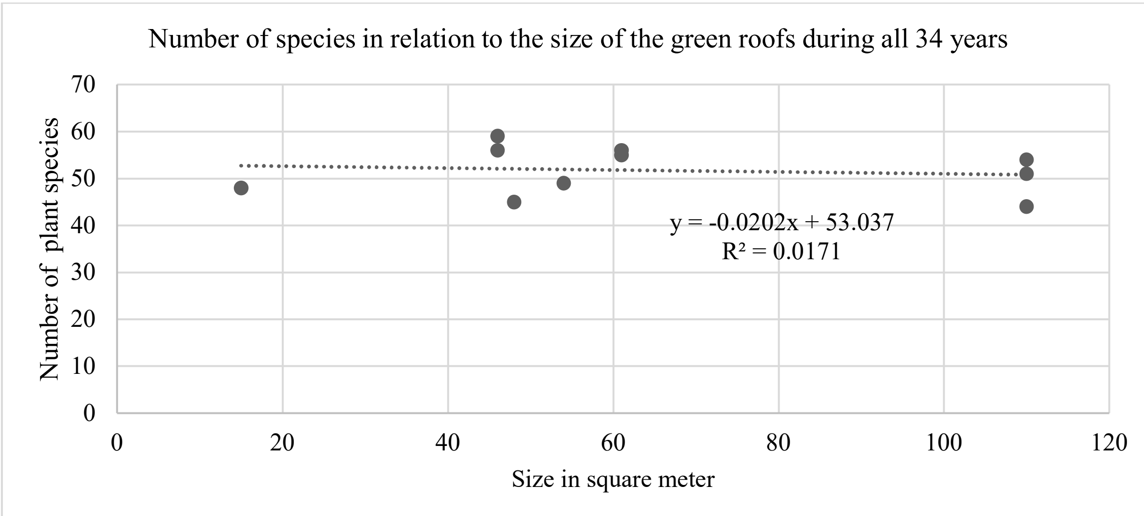

Figure 3. The relation between number of vascular species and roof size, as an average value over all years.

Similarity between the roofs

The correlation for the plant species across all 10 roofs is shown (Table 2). The high expected significance is confirmed. A slightly lower correlation is apparent for Roof 9 on the courtyard building at Paul-Lincke-Ufer 44a. The dominance of *Poa bulbosa* and high numbers of *Erodium cicutarium* are due the harsh windy weather conditions on this roof with fewer vertical structures that block wind. The absolute number of vascular plant species at this time was 124.

Table 2 Correlation between the ten roofs, with high correlation values.

		Roof 1	Roof 2	Roof 3	Roof 4	Roof 5	Roof 6	Roof 7	Roof 8	Roof 9	Roof 10
Roof 1	Pearson – Correlation	1	0.898**	0.966**	0.890**	0.861**	0.923**	0.919**	0.933**	0.846**	0.910**
	Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

How do the annual weather conditions influence the cover values, number of species, and the cover of *Allium*?

Over the total of 34 years, 16 were characterized as “wet” and 18 were characterized as “dry” when the weather data were analyzed. These data are prepared for the t-test analysis by SPSS (Table 3).

Table 3 Paired t-test procedures for the 16 wet and 18 dry years over the observation period by the criteria: cover value in % of all vascular plants, number of vascular plants per year, and coverage of *Allium* in %.

Species/ Treatment	x mean	Stand dev.	N roofs	Stand.-error mean	Paired –T-Test	Sig. (2-sites)
Cover of vascular plants-dry	87.0	5.98	10	1.89		
Cover of vascular plants-wet	90.5	3.78	10	1.20	-3.248	0.010*
Number of vascular plants-dry	14.1	1.85	10	0.59		
Number of vascular plants-wet	15.5	1.35	10	0.43	-3.50	0.007*
Cover of Allium- dry	48.7	9.42	10	2.98		
Cover of Allium -wet	52.6	12.16	10	3.85	-2.86	0.019*

The results of this test confirm that the rainier conditions significantly influence the criteria of vegetation coverage, with 3% more coverage being significant at the 1% level. In addition, the 1.5 more plant species for the years under wet conditions is also significant at the 1% level. *Allium* also benefits from the wet conditions with a higher coverage of about 4%, which means significant at the 2% level.

All information for Roof 1 is summarized (Figure 4), with the other nine roofs having similar graphs. The graph shows the general mechanism of colonization over time. First, it confirms the success in making the right plant selection in the turf mats. The central group of plants with the long bars over all times from *Poa compressa* to *Bromus tectorum* are dominant at all the years. It is also shows that some of these only persist for a few years at the beginning, such as *Dactylis glomerata* and *Koeleria pyramidata*, and are also accompanied by some pioneer weeds in the beginning, such as *Echinochloa crus-galli*, or *Poa annua*. On the other hand, over time additional introduced/spontaneous plants appear on the roof but only as accompanying plants with low cover values. Considering the goal of achieving long-term, complete, and low-maintenance green cover, the project was successful. In an attempt to achieve high biodiversity in line with recent aims of the green roof movement, it has relatively low values compared to other projects with the total number of 124 species. They sort in three categories of “pioneers”, “all time representatives” and accompanying species (Table 4).

DISCUSSION

This survey monitors a stabilized extensive green roof. There are some phases of annual changes, initially characterized by several accompanying plants. Annual variation in the biomass is connected to annual weather conditions. The amount of rain in the vegetative growth season significantly influences the vegetation cover. The pre-produced turf mats provide full vegetation cover for the pitched roofs as there are likely seasonal intra-annual changes that were not assessed here.

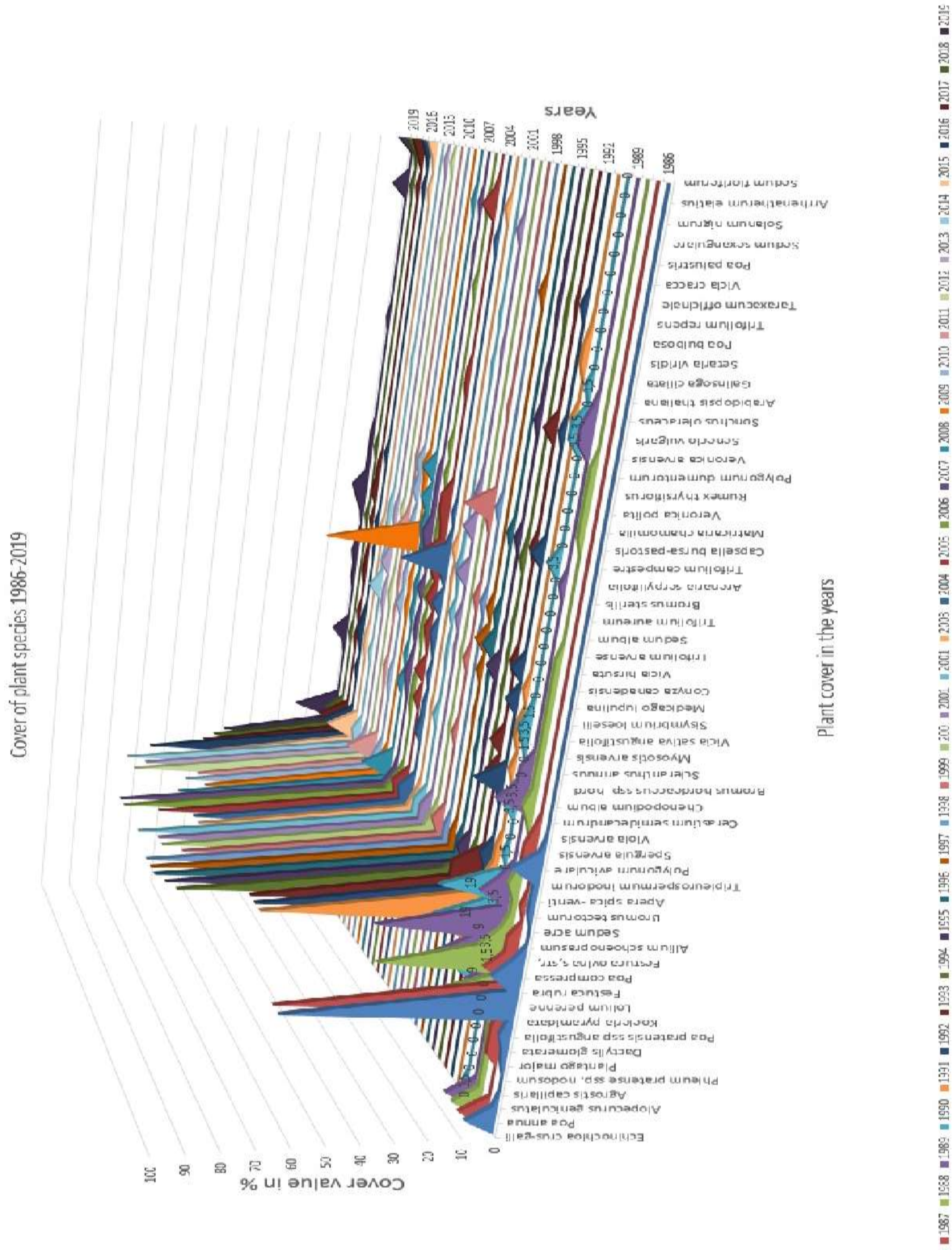

Figure 4. Roof 1 as an example, representative of all 10 roofs of this project. On the x axis are the plant species listed, but for the better readability only every second plant is printed. The y axis shows the cover value for the years, and the scale on the right hand shows the research years including the cover values of the years. The peak cover values of the time between 1986 and 2019.

Table 4. The total amount of the 124 plant species in the 34 observation years can be categorized into the following three main groups (Data from figure 4). The other plants are in less than 10 years present.

Pioneer species: of the first 3 year(s) such as:	All time present species (in 30-32 years): the basic composition of these roofs.	Frequent spontaneous species (in 23-10 of the 34 years). All other 99 are in less than 10 years present.
Echinochla crus-galli *Festuca rubra* *Lolium perenne* *Phleum pratense* *Poa pratensis*	*Allium schoenoprasum* *Bromus tectorum* *Festuca ovina* *Poa compressa* *Sedum acre*	*Arenaria serpyllifolia* *Bromus hordeaceus* ssp. *hordeaceus* *Bromus sterilis* *Cerastium semidecandrum* *Medicago lupulina* *Myosotis arvensis* *Sedum album* *Sedum sexangulare* *Sisymbrium loeselii* *Trifolium arvense* *Trifolium campestre* *Vicia hirsuta* *Vicia sativa angustifolia*

The vegetation is adapted to this extreme slope, dry and windy location in the roof top-level by the life forms of the dominant species. Examples are here, the bulb as a storage organ (*Allium*), the storage rhizome of *Poa compressa*. Succulence at survive strategy of *Sedum acre*, and the awn-proven seeds of *Bromus tectorum* or the long root system of *Festuca ovina*. That makes these plants the most successful competitors in most of extensive green roof projects in Berlin (Koehler and Poll 2010) and in Germany in general (Catalano et al., 2016; Thuring and Dunnet, 2014). The important feature is the stable, underlying species collection over the entire period.

Green roof technology competes with typical hard roof covers, such as clay roof tiles with more than 80 years life expectancy or concrete roof tiles, which have a life span of 40–50 years. This primary requirement to last a similar period is confirmed here over more than 30 years' observation and no visible damage during this time (Figure 5). The main aim that green roofs can also compete with hard-roof versions of shingles on pitched roofs is confirmed. This also confirms the observation of the remaining older green tar roofs from the beginning of the 20th century (Koehler and Poll 2010).

Over the observation period, the annual care of the roof vegetation was limited to an annual survey and minor replanting around the chimneys and near some technical installations. The climate conditions are characterized by long dry periods in summer and harsh winter conditions, similar to conditions that are typical across wide areas of the United States, meaning that the general findings are relevant.

The project results are best compared to other publications about green roofs in Germany. The best comparison is with the housing terrace project in Hannover that was completed in 1985 (Catalano et al., 2016). Pre-produced turf mats were installed here as well, with a grass mixture of *Festuca rubra, Festuca ovina, Agrostis capillaris, Lolium perenne*, and *Poa pratensis*. The plant species observations were performed in 1987, 1999, and 2014. Between

1987 and 1999 the number of species increased, while in 2014 the species were stable at the same level, which means all ecological niches are covered. The grasses that were initially present were largely substituted by incoming local spontaneous plants. The decrease in *Festuca rubra, Agrostis capillaris, Lolium*, and *Poa pratensis* are similar to the results seen in Berlin.

Figure 5. The PLU (Paul-Lincke-Ufer) roofs today: the green roofs are well developed, and the climber has covered all the facades. All areas are in good condition and will thrive for years to come.

Another example are studies from the Stuttgart region, conducted by Thuring and Dunnett (2014 and 2019), for which the original documents detailing the initial plant species are available. The documentation was based on only one plant species observation at the end of the 30-year period. It helps to compare the nine projects of Thuring, which have different sizes, inclinations, and locations, with each other. The basic result is that, again, a number of the initial species are no longer present, but the roofs overall have an adequate layer of vegetation and will thrive for the next few years. The adaption strategies of competition winning species are related to stress-tolerance and preferred ruderal strategies.
Koehler and Poll (2010) compared the PLU roofs as an example of "modern extensive green roofs" with the older Berlin tar-paper green roofs and concluded that the modern mixtures of the soils are a significant factor behind the higher plant species richness.

This research contributed to the survival and maintenance questions of extensive green roofs on multi-story buildings with poor accessibility for gardeners. The lessons learned from this project are that extensive green roofs can be installed as long-lasting technology. The next important feature about the eco-functionality of extensive green roofs is the connection for more plant and animal biodiversity on roofs and the surrounding ground space areas. The analysis of several green roof projects (Koehler and Ksiazek-Mikenas, 2018, Ksiazek-Mikenas et al. 2018) reveals some solutions that can effectively enhance such biodiversity, such as a change in growing materials, substrate depths, developing several eco niches, and targeted maintenance.

Looking back over green roof development, from the visions of the team led by Martin Küenzlen to today, we see a shift from a simple and environmental ecological feature to a multi-purpose solution with several benefits, as stated in the publication by Oberndorfer et al. (2007) and the summary of evidence of Manso et al. (2021).

In contrast to a wide range of surveys of flat green roofs, surveys such as this one on pitched roofs are the minority, but as shown here they can be maintained over decades. A reduction in the plant species richness must be accepted, however. The technology of turf mats has become more specialized, with locally adapted mixtures being produced that are tailored for the specific projects. The lesson is that the normal flat roofs in Germany and the USA are the typical green roof solution, with extra benefits for residents and neighbors. Roofs with a pitch of up to 45° are easy to manage, but steeper constructions should be executed using living wall technology.

ACKNOWLEDGEMENTS

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Additional Links

https://fhxb-museum.de/xmap/media/S7/T1791/U26/text/fhxb_spk_gutber_00036a_72.pdf
https://gruendach-mv.de/ (homepage of the author).
https://www.stadtentwicklung.berlin.de/bauen/oekologisches_bauen/de/bausteine/index.shtml (Webpage with a number or research paper, case studies of eco-buildings in Berlin, and the environmental mapping system with a link to current projects and reports.
https://berlin.museum-digital.de/index.php?t=serie&serges=28 (a collection of environmental studies from the IBA)

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