06.11 Green Roofs 2020

Introduction

Green roofs have a positive impact on the environment and therefore help to counteract the impairment of the natural balance in conurbations. They reduce rainwater runoff, create evaporation surfaces and may even increase biodiversity (DBU 2011). Offering the possibility of creating additional green spaces for recreation and activity, green roofs contribute to improving the urban residential environment.

Roof greening measures, as an element of adding green roofs to both new and existing buildings, aim to **relieve the burden on the sewage system, improve the air quality, cool the urban climate** as well as strengthen the biodiversity. Furthermore, roof greenery reduces noise levels and adds greatly to the cityscape. These positive effects also help to boost the urban population's health when it comes to climate adaptation (SenStadtUm 2016, SenStadtUm 2016a).

At the national level, this approach is supported by an initiative of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), which highlights the role of green roofs and facades for the health of the urban population in their green paper "Green Spaces in the City" (BMUB 2015).

Green roofs may reduce the problems of an impervious city, such as urban heat islands. As an element of rainwater management, they may also relieve the burden on surface waters (SenSW 2017a). Planted roofs lead to a better retention of rainwater. The reduction in rainwater runoff alleviates the strain on the sewage system (SenStadt 2010).

Since the year 2000, domestic wastewater and rainwater charges have been billed separately. Rainwater charges are based on the impervious areas of a property. Areas with no or very little impact on rainwater discharge are either disregarded or taken into account partially in the calculation process. For green roofs, for example, only 50 % of the area is included in the calculation (SenJust 2016, BWB 2021).

Greenery on roofs and facades has been a part of Berlin's story for a long time. At the beginning of the 19th century, Berlin already featured about 2,000 green roofs, in the form of wood-concrete roofs (Ahrendt 2007).

In West Berlin, a "courtyard greening programme" was initiated in 1983. The goal was primarily to mitigate green space deficits in the inner city. The programme offered funding for courtyard, facade and extensive roof greening measures. East Berlin also had a "courtyard greening programme" in the 1980s. Starting in 1990, the programme, which had been developed in 1983, was carried out in the entire inner-city area of Berlin. This was followed by guidance on how to preserve and maintain the facilities. The programme ran from 1983 to the end of 1995. During this period, 1,643 projects were approved, 740,000 m² of courtyard and facade areas, and 65,000 m² of roof areas were greened (Reichmann 2009).

As early as 1990, ecological requirements were defined in the guidelines on public funding for social housing, stipulating that resource conservation and environmental compatibility should be considered in building projects. Eligible for funding were, for example, vegetation concepts for facade and roof greening, as well as particular ecological open space concepts and their implementation.

Since 1992, ecological planning criteria have been in place for competitions. They state that "compensatory measures, such as roof gardens or roof and facade greening are particularly helpful in densely built-up inner-city areas […]" (SenStadt 2019). Green roofs and facades are also important components of general ecological concepts focussing on buildings; exceptional ecological building projects in Berlin may be found here (SenSW 2017b, SenSW 2017c).

The biotope area factor (BAF) is a special way of securing "green qualities" in the inner city to mitigate open space deficits and reduce environmental burdens. In Berlin, the BAF may be stipulated as a legal ordinance in a landscape plan. It describes the area share of a property that is vegetated or plays a role in the natural balance, therefore including green roofs (SenUVK 2021).

Since 2019, the "GründachPLUS" (Green Roof PLUS) funding programme, formerly known as "1.000 grüne Dächer" (1,000 Green Roofs), has been promoting the planting of greenery (> 100m²) on existing buildings, particularly in high-density urban quarters (SenUVK 2019). As there is currently no legal obligation to add green roofs to existing buildings, public funding is a very important measure here (Abgeordnetenhaus Berlin 2022).

The available data on existing green roofs may be used for various purposes. They may also be used as a basis for rainwater management concepts in urban areas and as a data basis for climate modelling. The data also serves as a basis for continuously monitoring the development of green roofs. Moreover, the available inventory of green roofs may also be used to develop future green roof strategies. For this purpose, it would also be important to determine the untapped green roof potential in the city.

Statistical Base

Multispectral remote sensing data is particularly suitable for capturing green roofs. The “view from above” allows a spectral differentiation of roof surfaces and materials. Essential data that was needed for an accurate classification was available in the form of current, high-resolution, digital colour-infrared orthophotos and elevation data, as well as building and roof outlines.

The following information formed the statistical base:

- Digital colour infrared TrueOrthophotos 2016 (TrueDOP20CIR) and a normalised Digital Surface Model (nDSM), aerial photography flights on August 1, 8, 12, and 16, 2020 (SenSW 2020a)
- Building geometries as well as underground car parks of the Official Real Estate Cadastre Information System (ALKIS) as of May 2022 (SenSBW 2022),
- NOT-ALKIS buildings: freestanding buildings, as of 2021
- Urban and Environmental Information System (ISU5) – spatial reference and land use data, as of December 31, 2020 (SenSW 2020b)

In order to avoid overlaps with ‘building areas’, only such underground car park area shares without superstructures were used of the ‘underground car park areas’ listed in ALKIS.

In addition to the ALKIS building dataset, a classification of the 2020 nDSM was carried out, facilitating the development of a NOT-ALKIS building dataset (SenSW 2020b, SenSW 2021a). The buildings thus determined were used to supplement the building data basis for selected area types (single-family homes, row houses and duplexes, villas, allotment gardens, weekend cottages and rental-flat buildings of the 1990s and later). Any freestanding NOT-ALKIS buildings on these areas were selected for the data basis in addition, to facilitate a statistical evaluation by building. Any NOT-ALKIS building parts that merely supplement an ALKIS ‘building area’ could therefore not be included.

The ‘building’ data base (ALKIS and NOT-ALKIS buildings combined) comprises a total of 629,666 objects. It should be noted that about 105,000 of these buildings represent very small objects of less than 20 m^2 (e.g. garages or allotment garden huts).

Methodology

The method that was developed for acquiring data on green roofs consists of two steps:

- an automated preliminary mapping, including the determination of reference areas, and
- a review and correction of the preliminary mapping results by interpreting aerial images (visual post-processing).

The following diagram shows the details of the workflow. A comprehensive description of the procedure may be found in the final report (Pauligk & Stöckigt 2022).

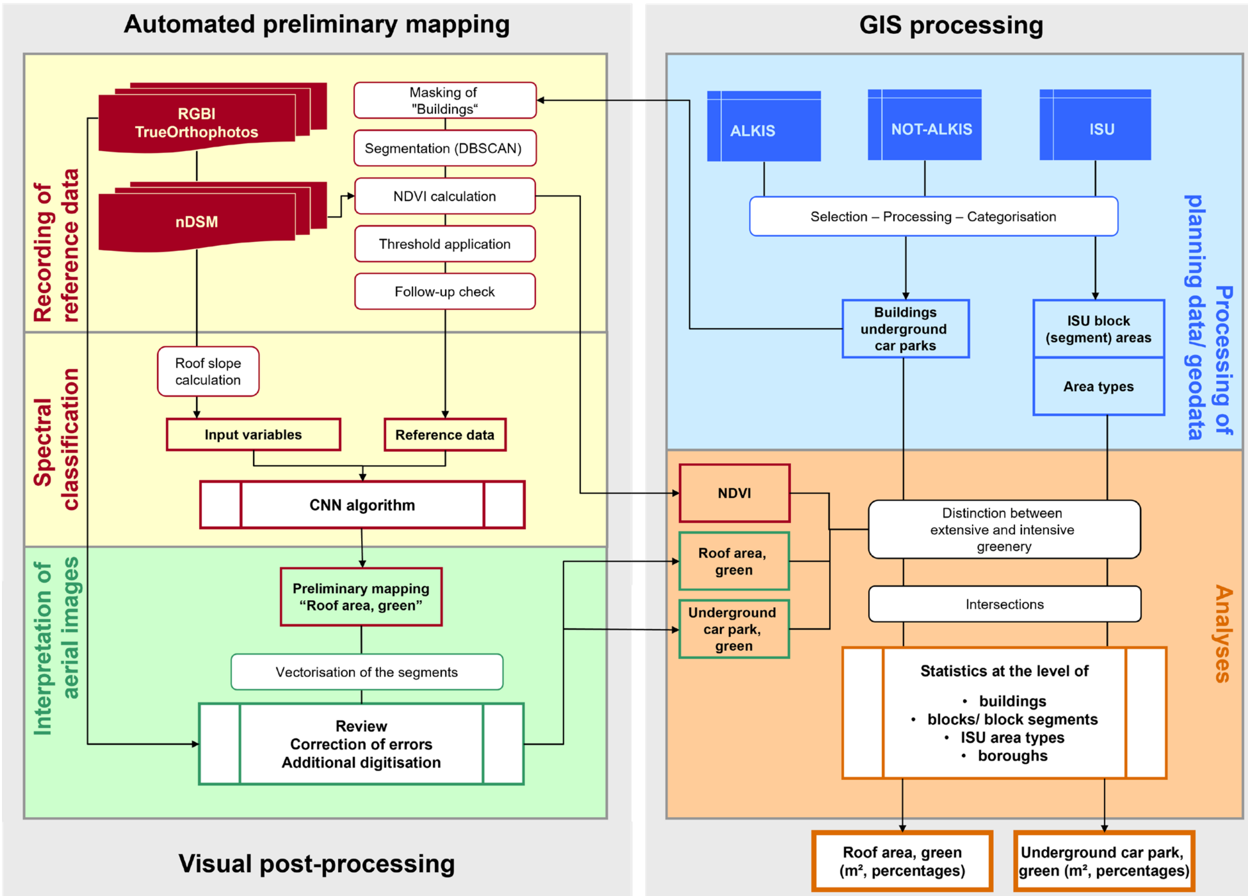


Fig. 1: Workflow – capturing data on the green roof inventory in the State of Berlin, 2020

Automated preliminary mapping

As part of the automated preliminary mapping, a supervised classification was carried out to predict the location of green roofs. For this, detailed reference data had to be recorded for a section of Berlin (~2,000 ha). The process of deriving this reference data was based on building outlines, which defined the areas for analysis, i.e. only these areas were searched for vegetation. Buildings that were not listed in the data bases (ALKIS, NOT-ALKIS) were not analysed. A combination of unsupervised classification and threshold analysis, using the Normalised Difference Vegetation Index (NDVI), was found to be a suitable approach for detecting green roofs within the analysed areas.

Initially, density-based clustering (DBSCAN) was applied to the areas within building outlines that were analysed. DBSCAN is an unsupervised algorithm that groups pixel values together within a feature space, based on their spatial proximity, therefore dividing them into segments. In addition to the spectral data of the TrueOrthophoto, the object height (nDSM) was also factored into the analysis. The segments were then characterised by their NDVI. An average NDVI of more than 0.1 led to a preliminary detection of a green roof. The NDVI is a synthetic channel that combines information from the near-infrared (NIR channel) and the red spectrum (red channel), which highlights vegetation areas in particular. Numerous studies found that this additional channel was useful for differentiating between surfaces with and without vegetation, and for classifying degrees of impervious coverage (Coenradie et al. 2021, Coenradie & Haag 2016a). As the section used for deriving reference data was rather small (~2000 ha), the preliminary detection of green roofs were adjusted easily, based on a visual correction. The corrected data was then used as an accurate reference in the supervised classification.

A Convolutional Neural Network (CNN) was used for the supervised classification. It is a type of neural network that has become popular in the classification of image data, as its prediction also considers spatial structures within the image in addition to the spectral signature (Kattenborn et al. 2021). One of the most widely used CNN architectures is the U-Net, which was also used to detect green roofs in this project (Ronneberger et al. 2015). In addition to the reference data described, the supervised classification also requires relevant input variables. These include the spectral bands of the orthophoto, the normalised Digital Surface Model (nDSM) and the slope of the roof surface derived from the latter. After training the algorithm, the model was applied to the rest of the area to be investigated, which simplified the subsequent mapping process. Due to the high data requirements of neural networks and the rather small data pool of derived reference data, post-processing was an essential part of the workflow. Fig. 2 presents the prediction of the model for a small sample area.

Fig. 2: Supervised classification results, left: TrueOrthophoto, 2020; right: automated preliminary mapping of the green roof inventory (green)

Visual post-processing

The intermediate results of the automated preliminary mapping were reviewed and corrected based on aerial images.

The interpretation and mapping process was based on the following rules:

- All vegetated roof areas count as green roofs, regardless of whether they were deliberately designed as green roofs (which cannot always be discerned) or came about due to spontaneous vegetation.
- Large plant tubs and roof gardens are mapped as green roofs.
- Pre-mapped areas are the main focus of the review; large green roofs that were missed are then digitised upon detection.
- If a green roof area also includes a solar system, it is still recorded as a green roof area in its entirety.
- The recording of a green roof is considered sufficient if more than two thirds were detected during the preliminary mapping process. In this case, no post-processing is necessary. If less than two-thirds of a green roof were mapped, the green roof is digitised manually, based on the exact areas.
- If a green roof may not be discerned due to shadows or a canopy cover (this mainly concerns garage roofs), any preliminary mapping is deleted. This does not apply to roof areas overshadowed by trees, for which a green roof was detected in 2016. In these cases, TrueOrthophotos from February 2021 are reviewed. If a green roof is discernible at the point when trees are without foliage, it is mapped subsequently.
- Very narrow linear elements or paths do not need to be excluded.

After all areas were reviewed, those green roofs with green areas of more than 10 m² per building were selected. This allowed for individual pixels and tiny areas to be included; it is the total area per roof that was important in the end. If a roof had a green roof area of less than 10 m^2, it was deleted. Subsequently, the green roof areas were divided into intensive (NDVI >0.162) and extensive areas (NDVI <= 0.162) using an NDVI threshold. Depending on the category share of the green roof (> 50 %), the entire roof was either categorised as an ‘intensive’ or ‘extensive’ green roof. An intensive green area is characterised by dense and vital vegetation. An extensive green area is characterised by sparser and possibly drier vegetation.

The information was linked to additional geodata. Based on this, the following result layers could be established, which may also be accessed in the Geoportal:

- **green roof area (intensive/ extensive),**
- **building floor area and**
- **block (segment) area of the ISU with data on greenery**.

Map Description

In Berlin, there are 629,666 buildings, 20,446 (3.2%) of which are underground car parks without superstructures featuring green roofs or green roof areas larger than 10 m². In total, 656 ha of all roof areas are greened (5.4 %) (Tab. 1). Since 2016, the number of buildings with green roofs has therefore increased by 0.2 %. The ‘green roof’ area share even rose from 3.9 % to 5.4 %. Overall, the green roof area grew by 165 ha. A look at the map reveals that green roof areas are concentrated in the inner city of Berlin.

Tab. 1: Green roof areas in Berlin

		Number of buildings		Green roof area				Floor area of the buildings	
				intensive		extensive			
			%	m²	%	m²	%	m²	%
2016	existing green roof area	18,368	3.0	605,507	0.6	3,397,176	3.3	11,847,832	11.5
	Berlin total	604,865		4.002.682 / 3,9				103,299,727	
2020	existing green roof area	20,446	3.2	1,482,468	1.4	4,169,584	4.0	13,985,119	13.4
	Berlin total	629,666		5.652.053 / 5,4				104,599,458	

A building's greenery is classified as either "intensive" or "extensive", based on w hichever share is larger. If a building has an "extensive" green roof area of >50 %, the entire green roof area is considered "extensive" in the calculation process.
In 2020, the building data base contained about 540,000 ALKIS buildings and 88,000 NOT-ALKIS buildings.

Tab. 1: Green roof areas in Berlin in 2016 and 2020

A building's greenery is classified as either “intensive” or “extensive”, based on whichever share is larger. If a building has an “extensive” green roof area of >50 %, the entire green roof area is considered “extensive” in the calculation process.

In the following, analyses are presented for three spatial levels – building, ISU block (segment) area and borough.

Buildings

Buildings were classified into six “building use” categories based on the use information from ALKIS and NOT-ALKIS. Table 2 and Figure 3 illustrate the size and percentages of building uses that include green roofs.

With percentages ranging between 22 and 30 % (Fig. 3), green roofs [m²] are relatively evenly distributed across the building uses “Residential” (incl. weekend cottages), “Non-residential buildings” (e.g. schools, town halls, retirement homes, administrative buildings), “Office buildings, commercial” and “Underground car parks without superstructures”. Compared to rooftop greenery, that of underground car parks tends to be more comprehensive and denser (Fig. 3). The ratio of intensive to extensive greenery on underground car parks is about 80 % to 20 %, on building surfaces it is the reverse.

In addition, Table 2 identifies **potential for future green roofs**. So far, only 3.4 % of buildings in the **"Office buildings, commercial"** category, which are expected to have flat roofs for the most part, have green roofs. The green roof potential is therefore high. By contrast, and, as expected, this potential has been tapped into much more at **77 % in the category of underground car parks** without superstructures. This is the case, although the proportion of greenery varies across the roof surfaces of underground car parks (Tab. 2).

One might also expect a larger proportion of green roofs on garages and sheds. This is complicated by the issue, however, that green roofs frequently remain undetected on these often rather small rooftops due to large tree canopies and are therefore not recorded during the mapping process. As a result of the TrueOrthophotos recorded in summer (August), this occurred more frequently in the course of the 2020 mapping compared to the 2016 mapping. The actual proportion of green roofs is therefore assumed to be higher in this building use category.

Tab. 2: Distribution of green roof areas by building use													
Building use	**Number of buildings with green roof areas**						**Number of buildings without green roof area**	**Total number of buildings**	**Green roof area [m²]**			**Building floor area [m²]**	**Green share [%]***
	≤25*	**>25-50***	**>50-75***	**>75***	**Total**	**Total [%]**			**intensive**	**extensive**	**Total**		
Residential	2,603	2,614	3,278	1,581	10,076	3.1	312,219	322,295	160,656	1,532,105	1,692,761	55,933,797	3.0
Non-residential building	835	538	642	801	2,816	5.2	51,437	54,253	179,340	1,119,492	1,298,832	25,484,178	5.1
Office building, commercial	526	450	457	473	1,906	3.4	54,184	56,090	77,918	1,175,135	1,253,053	13,168,485	9.5
Underground car park w ithout superstructures	322	617	1,033	1,245	3,217	76.9	968	4,185	1,013,929	295,632	1,309,561	2,704,467	48.4
Garage, shed	37	117	428	1,765	2,347	2.2	102,432	104,779	49,021	34,802	83,823	3,409,259	2.5
Other	14	33	30	7	84	0.1	87,980	88,064	1,604	12,418	14,022	3,899,272	0.4
Total	**4,337**	**4,369**	**5,868**	**5,872**	**20,446**	**3.2**	**609,220**	**629,666**	**1,482,468**	**4,169,584**	**5,652,052**	**104,599,458**	**5.4**

* Ratio of green roof area to building floor area [%]

Green areas are divided into intensive and extensive areas at building level. It should be noted that a threshold w as applied to make this distinction. The threshold w as based on the spectral properties of the orthophotos from August 2020. Some vital green areas may thus have been categorised as "intensive", although they are actually extensive green roofs.

A building's greenery is classified as either "intensive" or "extensive", based on the larger share. If a building has an "extensive" green roof area of >50 %, the entire green roof area is considered "extensive" in the calculation process.

This evaluation is based on the use data of ALKIS buildings. Use data w as not available for NOT-ALKIS buildings. These buildings are listed under "Other".

Discrepancies may occur due to rounding.

Tab. 2: Distribution of the green roof areas by building use, 2020

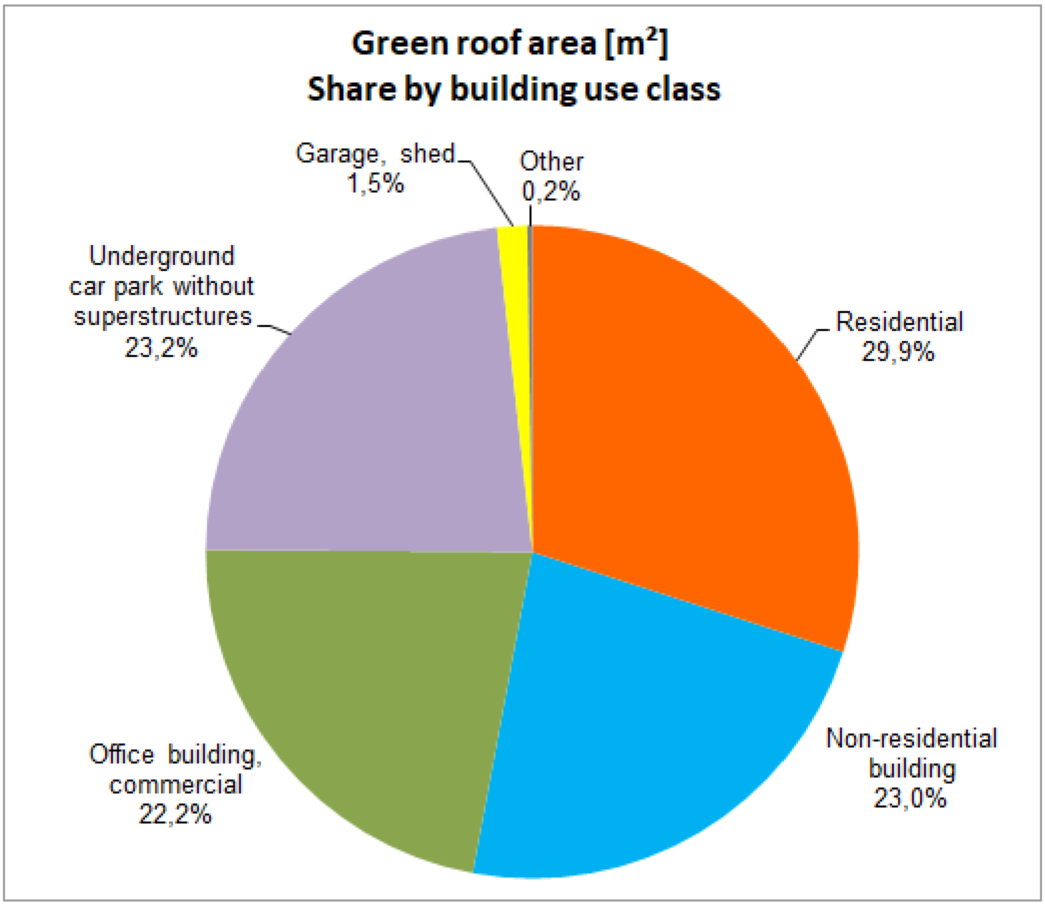


Fig. 3: Green roof area [m²] – share by building use class, 2020

Block (segment) areas

By linking the buildings to the block (segment) areas of the ISU, analyses may also be carried out based on the ISU area types (cf. Tab. 3).

With a total of more than 30 ha each, the area types "Settlement from the 1990s or later (73)", "Commercial and industrial area, large-scale retail with sparse development (30)", "Closed block development, rear courtyard, 5-storeys (2)", "Core area (29)" and "Closed and semi-open, de-cored block development, post-war gap closure (7)" exhibit the largest green roof areas in absolute terms. The two area types "City square / promenade (54)" and "Settlement from the 1990s or later (73)" stand out with a green roof proportion of 26.2 and 27 %, respectively, in relation to the building floor area. The area type "Detached single-family homes with yards (23)" also has a large building inventory; however, it only has a green roof share of 1.1 % in relation to the building floor area. This suggests that private residential areas have a lot of untapped potential for green roofs in general, although it is limited to roofs that are suitable for greenery (flat or slightly sloping roofs).

Tab. 3: Distribution of green roof areas by ISU area type										
Area type of 2020		Number of buildings with green roof			Green roof area [m²]			Total number of buildings	Total building floor area [m²]	Ratio of green roof area to building floor area [%]
		intensive	extensive	Total	intensive	extensive	Total			
1	Dense block development, closed rear courtyard, 5-6-storeys	94	360	454	17,418	55,119	72,538	4,899	1,800,118	4.0
2	Closed block development, rear courtyard, 5-storeys	692	2,339	3,031	150,029	392,657	542,685	28,666	9,197,774	5.9
3	Closed and semi-open block development, decorative and garden courtyard, 4-storeys	234	346	580	38,730	54,253	92,983	10,951	2,756,669	3.4
6	Mixed development, semi-open and open shed courtyard, 2-4-storeys	50	117	167	6,121	15,874	21,994	4,824	684,227	3.2
7	Closed and semi-open, de-cored block development, post-w ar gap closure	444	890	1,334	170,080	224,227	394,307	11,484	3,885,130	10.1
8	Heterogeneous inner-city mixed development, post-w ar gap closure	147	300	447	58,105	96,958	155,063	3,451	1,246,368	12.4
9	Large estates and single-tow er high-rise buildings, 4-11-storeys	241	447	688	73,862	147,858	221,720	10,726	5,160,501	4.3
10	Block-edge development w ith large quadrangles, 3-5-storeys	96	141	237	28,140	43,768	71,908	10,051	3,040,205	2.4
11	Row development w ith landscaped residential greenery, 3-6-storeys	416	524	940	86,359	128,507	214,866	20,627	5,494,552	3.9
12	Old school (built before 1945)	23	77	100	3,098	20,018	23,116	1,740	850,042	2.7
13	New school (built after 1945)	92	216	308	29,224	130,022	159,245	3,268	2,153,979	7.4
16	Uncovered sports facilities	30	69	99	5,020	40,012	45,032	2,890	825,537	5.5
17	Covered sports facilities	22	37	59	3,925	29,410	33,336	1,417	456,616	7.3
21	Village-like mixed development	22	35	57	2,276	4,599	6,874	7,482	739,695	0.9
22	Row houses and duplexes w ith yards	244	1,062	1,306	22,817	55,522	78,338	57,406	3,595,042	2.2
23	Detached single-family homes w ith yards	1,168	1,260	2,428	84,286	99,209	183,495	248,194	17,416,763	1.1
24	Villas and rented villas w ith park-like gardens	516	370	886	54,036	35,510	89,545	27,585	3,036,434	2.9
25	Densification in single-family home areas, mixed development w ith yards and semi-private greening	258	298	556	38,307	39,269	77,576	16,940	2,084,934	3.7
27	Cemetery	19	33	52	3,144	5,878	9,022	1,031	137,652	6.6
29	Core area	134	421	555	59,820	315,766	375,586	2,214	2,433,629	15.4
30	Commercial and industrial area, large-scale retail w ith sparse development	156	686	842	59,365	599,537	658,902	16,350	11,395,480	5.8
31	Commercial and industrial area, large-scale retail w ith dense development	67	295	362	35,055	275,753	310,808	3,619	4,671,293	6.7
32	Utilities area	14	46	60	2,839	14,640	17,479	2,259	1,223,898	1.4
33	Mixed-use area, mostly crafts and small business, w ith sparse development	83	216	299	16,295	61,503	77,798	6,069	1,398,403	5.6
36	Tree nursery / horticulture	5	5	10	377	583	960	347	111,194	0.9
37	Allotment garden	12	23	35	1,145	2,577	3,722	67,854	3,154,629	0.1
38	Mixed-use area, mostly crafts and small business, w ith dense development	44	134	178	12,514	46,180	58,693	1,532	634,562	9.2
41	Security and order	13	32	45	5,357	18,117	23,475	1,284	907,999	2.6
43	Administrative	49	125	174	34,895	84,628	119,522	1,122	1,141,105	10.5
44	University and research	26	123	149	2,993	114,479	117,473	1,403	1,126,288	10.4
45	Culture	16	41	57	11,647	21,456	33,103	618	598,254	5.5
46	Hospital	47	132	179	13,914	102,324	116,238	1,415	1,217,690	9.5
47	Children's day care centre	8	30	38	2,227	10,117	12,343	617	279,479	4.4
49	Church	7	10	17	1,312	3,035	4,347	529	170,645	2.5
51	Other youth facilities	4	19	23	327	5,474	5,801	488	145,902	4.0
53	Park / green space	63	26	89	2,623	11,031	13,655	1,514	177,596	7.7
54	City square / promenade	1	3	4	4,185	2,854	7,039	86	26,918	26.2
55	Forest	5	7	12	607	1,105	1,713	1,088	103,205	1.7
56	Agriculture	0	1	1	0	40	40	122	24,682	0.2
57	Fallow area	2	4	6	53	1,134	1,187	471	47,653	2.5
58	Camping ground	0	1	1	0	172	172	125	9,589	1.8
59	Weekend cottages and allotment-garden-like areas	16	13	29	877	1,956	2,833	21,734	997,292	0.3
60	Miscellaneous and heterogeneous public facilities and special-use areas	61	145	206	11,813	64,087	75,900	2,908	1,418,195	5.4
72	Row development w ith architectural green strips, 3-5-storeys	69	67	136	10,015	12,519	22,534	7,338	1,663,848	1.4
73	Settlement from the 1990s or later	624	2,467	3,091	311,701	755,557	1,067,259	9,931	3,951,979	27.0
91	Parking area	47	8	55	1,020	7,033	8,053	438	84,292	9.6
92	Railw ay stations and railw ay grounds, w ithout track area	4	9	13	1,032	6,184	7,217	629	470,022	1.5
93	Airport	2	9	11	363	2,975	3,338	127	159,734	2.1
94	Other traffic areas	1	6	7	27	4,597	4,624	141	36,693	12.6
98	Construction site	0	3	3	0	349	349	112	32,763	1.1
99	Track area	2	3	5	1,004	749	1,753	445	99,680	1.8
100	Water body	2	2	4	711	97	808	91	6,558	12.3
Buildings in 'road areas'		14	7	21	1,382	2,306	3,688	1,014	116,071	3.2
Total		**6,406**	**14,040**	**20,446**	**1,482,468**	**4,169,585**	**5,652,053**	**629,666**	**104,599,458**	**5.4**

Green areas are divided into intensive and extensive areas at building level. It should be noted that a threshold w as applied to make this distinction. The threshold w as based on the spectral properties of the orthophotos from August 2020. Some vital green areas may thus have been categorised as "intensive", although they are actually extensive green
A building's greenery is classified as either "intensive" or "extensive", based on w hichever share is larger. If a building has an "extensive" green roof area of >50 %, the entire green roof area is considered "extensive" in the calculation process.

Tab. 3: Distribution of green roof areas by ISU area type

Boroughs

For the 2020 mapping, Figure 4 shows the green roof area in square metres by borough with the green roof area shares divided into percentage classes. It also presents the total green roof area for the year 2016. Mitte and Charlottenburg-Wilmersdorf clearly have the largest inventory of 'green roof areas'. Friedrichshain-Kreuzberg, however, has the highest proportion of 'green roof area' in relation to its building floor area (cf. Fig. 5). This diagram underlines the concentration of green roof areas in the inner city yet again, which is also due to the large number of flat roofs and Berlin roofs (asymmetrical roof with large (almost) flat areas) (Betz 2010). Figure 6 illustrates the overall low proportions of 'intensive' green roofs. The proportions of 'intensive' and 'extensive' green roof areas, however, vary across boroughs.

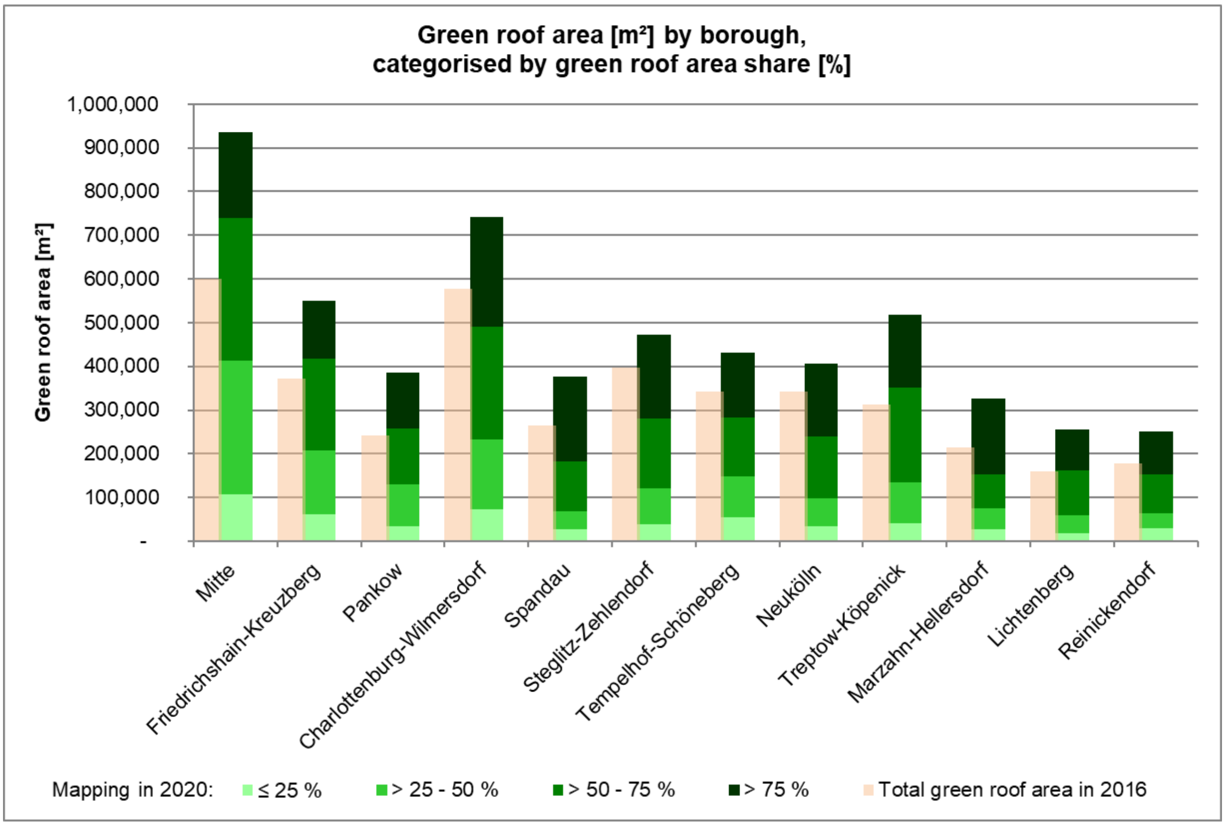


Fig. 4: Green roof area [m²] by borough, categorised by green roof area share [%], 2020

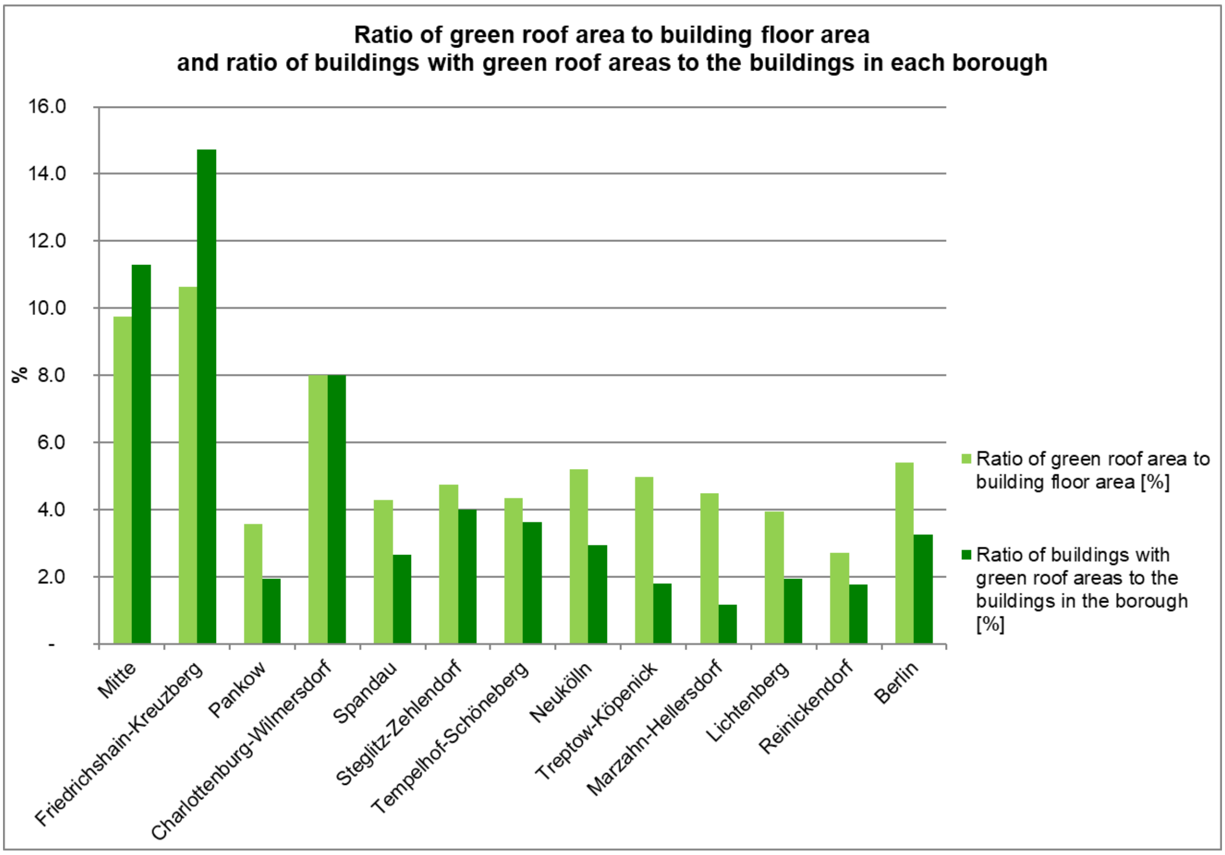


Fig. 5: Ratio of green roof area to building floor area and ratio of buildings with green roof areas to the buildings in each borough, 2020

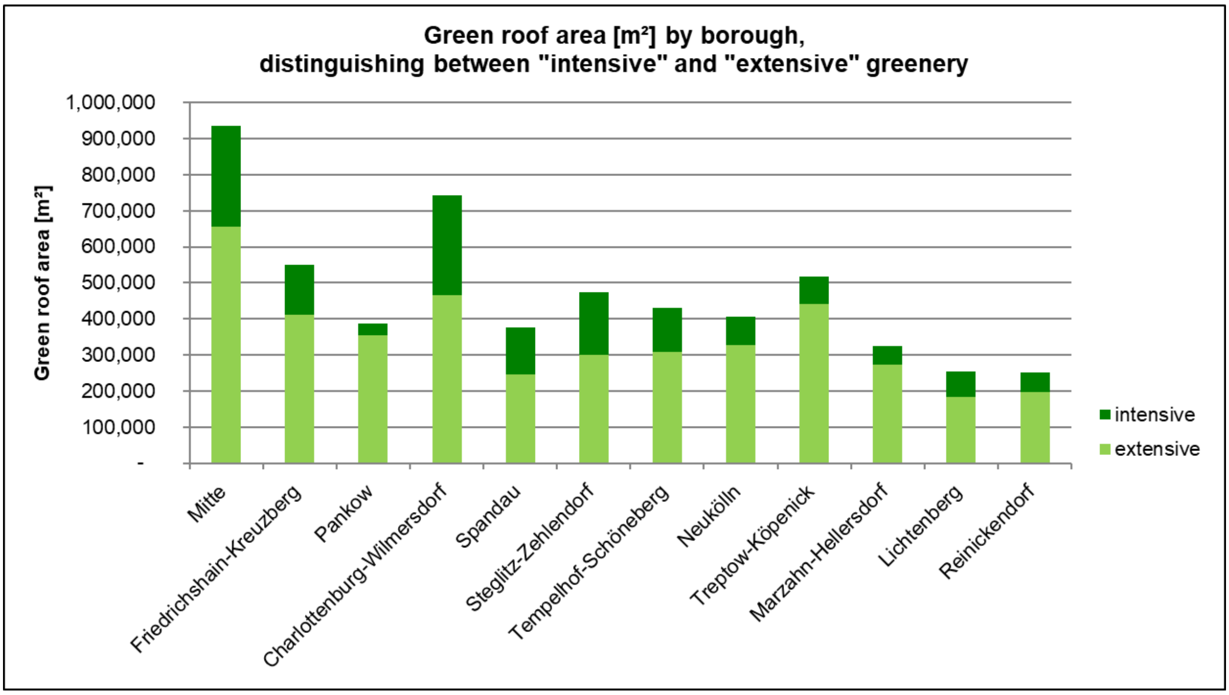


Fig. 6: Green roof area [m²] by borough, distinguishing between "intensive" and "extensive" greenery, 2020

Tab. 4: Distribution of green roof areas by borough																				
Borough		Number of buildings with green roofs					Green roof area [m²]							Number of buildings in the borough	Building floor area [m²]	Ratio of buildings with green roof areas to the buildings in the borough [%]	Ratio of green roof area to building floor area [%]	Green roof area in 2016 [m²]		
		≤25*	>25-50*	>50-75*	>75*	Total	≤25*	>25-50*	>50-75*	>75*	intensive	extensive	Total					Total in 2016	intensive	extensive
1	Mitte	716	694	734	376	2,520	107,502	306,103	326,239	194,919	277,432	657,331	934,763	22,336	9,579,485	11.3	9.8	600,267	67,523	532,744
2	Friedrichshain-Kreuzberg	497	535	591	294	1,917	62,715	144,554	209,477	133,413	137,428	412,730	550,158	13,022	5,168,114	14.7	10.6	372,087	59,079	313,008
3	Pankow	391	369	447	300	1,507	34,610	94,805	128,641	128,433	31,597	354,893	386,489	77,566	10,769,143	1.9	3.6	241,849	24,045	217,804
4	Charlottenburg-Wilmersdorf	717	582	638	594	2,531	72,994	159,328	257,797	251,875	276,670	465,324	741,994	31,555	9,268,164	8.0	8.0	576,841	105,875	470,966
5	Spandau	295	240	426	796	1,757	27,808	39,803	115,617	193,042	129,990	246,280	376,270	65,752	8,777,662	2.7	4.3	265,746	13,851	251,895
6	Steglitz-Zehlendorf	384	471	800	1,011	2,666	39,053	81,558	159,318	193,218	171,476	301,672	473,147	66,731	9,954,173	4.0	4.8	396,494	106,228	290,266
7	Tempelhof-Schöneberg	417	404	563	479	1,863	54,098	94,098	134,987	148,864	123,342	308,705	432,047	51,464	9,962,851	3.6	4.3	343,229	84,636	258,593
8	Neukölln	255	340	425	554	1,574	35,069	63,116	140,835	167,163	79,448	326,735	406,183	53,580	7,786,839	2.9	5.2	341,699	58,708	282,991
9	Treptow-Köpenick	216	323	522	516	1,577	40,417	94,910	217,079	165,512	76,703	441,214	517,917	87,463	10,382,757	1.8	5.0	313,501	49,027	264,475
10	Marzahn-Hellersdorf	108	108	202	294	712	27,099	47,794	77,867	173,280	51,487	274,551	326,038	60,514	7,250,867	1.2	4.5	213,521	9,930	203,591
11	Lichtenberg	110	110	193	187	600	18,305	41,036	101,665	94,562	72,326	183,241	255,567	30,780	6,477,828	1.9	3.9	158,922	13,070	145,852
12	Reinickendorf	231	193	327	471	1,222	28,620	34,555	89,040	99,264	54,569	196,910	251,479	68,903	9,221,575	1.8	2.7	178,525	13,535	164,990
Total		**4,337**	**4,369**	**5,868**	**5,872**	**20,446**	**548,288**	**1,201,660**	**1,958,561**	**1,943,544**	**1,482,468**	**4,169,585**	**5,652,053**	**629,666**	**104,599,458**	**3.2**	**5.4**	**4,002,682**	**605,507**	**3,397,176**

* Ratio of green roof area to building floor area [%]

A building's greenery is classified as either "intensive" or "extensive", based on whichever share is larger. If a building has an "extensive" green roof area of >50 %, the entire green roof area is considered "extensive" in the calculation process.

Tab. 4: Distribution of green roof areas by borough (Ratio of green roof area to building floor area [%])*

Change Analysis

The total area of green roofs increased by 165 ha between 2016 and 2020. The share of green roof areas therefore rose from 3.0 to 3.2 %. Almost half (approx. 75 ha) of the new green roof areas were added to buildings with residential use. This is reflected in the results of the area type analysis (cf. Tab. 3). About 53 ha of roofs were newly greened in the area type “Settlement from the 1990s and later”. Another 17 ha of green roof area were created in the area type “Closed block development, rear courtyard, 5-6 storeys”, which is mostly found in the inner city boroughs. The building types “Non-residential buildings and “Office buildings, commercial” received almost 40 ha of rooftop greenery, while it was about 28 ha for “Underground car parks without superstructures”.

An initial analysis at the borough level indicates that both the share of the number of buildings with green roofs in relation to the total number of buildings and the share of green roofs in relation to the floor area of the buildings increased across all boroughs. A differentiated analysis reveals that roof shapes suitable for greening are more likely to be found in the inner city boroughs, as are new green roofs. In the boroughs of Mitte and Friedrichshain-Kreuzberg, the number of green roofs in the total number of buildings increased by 2 and 3 % respectively. The green roof area in the borough of Treptow-Köpenick increased by about 20 ha, which is also remarkable (cf. Fig. 4). Here, a lot of new residential and commercial buildings with green roofs were built in the area of Adlershof.

The ‘change mapping’ below illustrates how the green roof area (in %) has changed in relation to the block (segment) area and how it is distributed across the city.

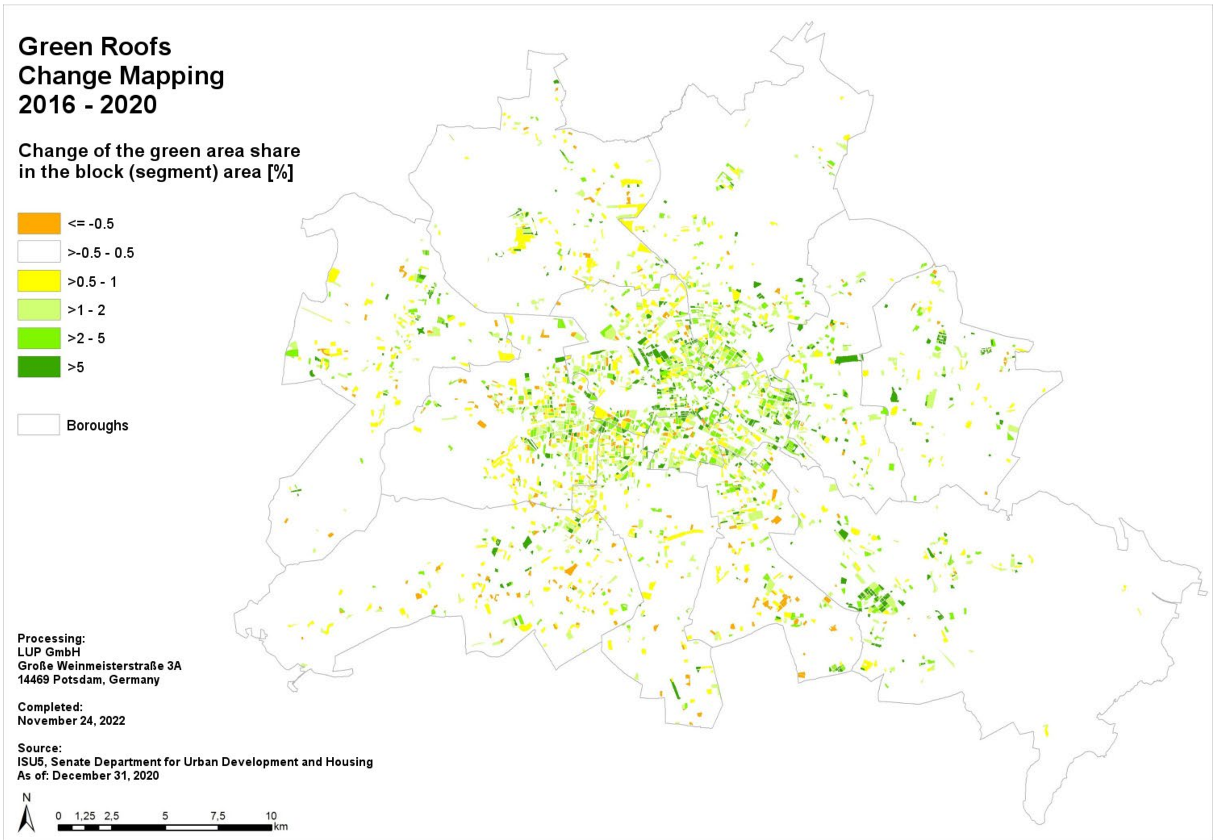


Fig. 7: Change mapping of the green roof area share in the block (segment) area [%] between 2016 and 2020

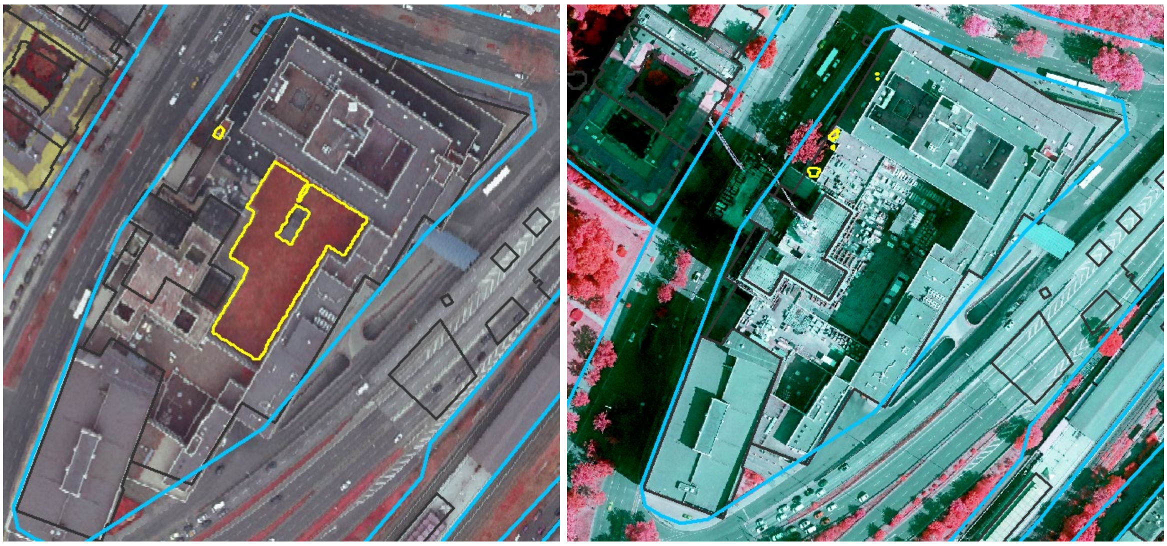
Overall, 86 block (segment) areas with a decreased green roof area share of more than 2 % are offset by 1,258 block (segment) areas with an increased green roof area share of more than 2 %. *Europacity,* north of the Hauptbahnhof (Berlin Central Station), has a strong concentration of block (segment) areas with new green roofs.

Top: green: block (segment) areas with an increased green roof area share > 5 %;
Bottom: section of new development with green roofs; background: TrueOrthophoto, 2020

Fig. 8: Example of Europacity: new development with green roofs, 2020

A new cluster of buildings with green roofs was also erected in the 'Science City' of Adlershof (borough of Treptow-Köpenick). These include commercially used buildings in the Science and Technology Park, university buildings on campus as well as modern apartment buildings.

An example of the removal of a green roof may be found in block 1200620771000000, at the corner of Schloßstraße/ Albrechtstraße. Here, a green roof was removed from the low part of a building and replaced by a storage area.



Yellow: green roof area, blue: block (segment) area, black: building
Left: 2016 mapping, right: 2020 mapping

Fig. 9: Example of the removal of a green roof on Schloßstraße

In 2016, Digitale Dienste Berlin, Büro für Angewandte Fernerkundung, und Luftbild Umwelt Planung GmbH (office for applied remote sensing) developed a method for recording green roofs in Berlin. It was used again successfully to update the data in 2020. The method facilitates a homogeneous, up-to-date city-wide recording of green roofs with sufficient accuracy. It is both operational and cost-effective. The use of TrueOrthophotos made it possible to improve the mapping accuracy compared to the recording of 2016. The tilting of buildings could thus be minimised. In contrast to the 2016 mapping, aerial images taken in the middle of summer were used. In addition, the vitality of the vegetation decreases in the summer, due to mounting stress of drought. Extensive green roof areas with sparse vegetation, which were still recognised as green roofs in 2016, might not have been recorded in 2020 as a result. Furthermore, due to the change in season between the 2016 and 2020 aerial photographs, there are phenological differences that reduce the comparability of the two mappings. This applies in particular to canopy covers of large deciduous trees.

Literature

[1] Abgeordnetenhaus Berlin [Berlin House of Representatives] (2022):
Schriftliche Anfrage des Abgeordneten Stefan Evers (CDU) vom 23.Juni 2022 zum Thema "Grüne Dächer in Berlin" [Written question by Stefan Evers (CDU) of 23 June 2022 on the subject of "Green roofs in Berlin"]. Drucksache 19/12330 [Printed matter 19/12330]
Internet:
https://pardok.parlament-berlin.de/starweb/adis/citat/VT/19/SchrAnfr/S19-12330.pdf [only in German]
(Accessed on 25 October 2022)

[2] Ahrendt, J. (2007):
Historische Gründächer: Ihr Entwicklungsgang bis zur Erfindung des Eisenbetons [Historical green roofs: Their development until the invention of reinforced concrete], Part I. Doctoral thesis at Faculty VI of the TU Berlin.
Internet:
https://depositonce.tu-berlin.de/bitstream/11303/1846/1/Dokument_1.PDF [only in German]
(Accessed on 28 November 2022)

[3] Betz, C.: (2010):
Methodenentwicklung für den Aufbau eines Gründachkatasters von Berlin am Beispiel des Bezirkes Friedrichshain-Kreuzberg [Developing methods for the creation of a green roof register of Berlin using the example of the borough of Friedrichshain-Kreuzberg], Master's Thesis at the Department of Landscape Sciences, Geomatics, Geodesy, and Civil Engineering of the Neubrandenburg University of Applied Sciences.
Internet:
http://digibib.hs-nb.de/file/dbhsnb_derivate_0000000845/Masterarbeit-Belz-2010.pdf [only in

German]
(Accessed on 28 November 2022)

[4] **BMUB (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit [Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety]) (ed.) 2015:**
Grünbuch Stadtgrün [Green Paper Green Spaces in the City].
Download:
https://www.bmwsb.bund.de/SharedDocs/downloads/Webs/BMWSB/DE/publikationen/wohnen/weissbuch-stadtgruen-en.pdf?__blob=publicationFile&v=3
(Accessed on 28 November 2022)

[5] **BWB (Berlin Waterworks) (2021):**
Satzung über die Erhebung von Gebühren und Kostenersatz für die zentrale öffentliche Abwasserbeseitigung (Abwassergebührensatzung - AGKS) [Statute on the levying of fees and reimbursement of costs for centralised public wastewater disposal (Wastewater Fee Statute, AGKS)]
Internet:
https://www.bwb.de/de/assets/downloads/abwassergebuehrensatzung-agks.pdf [only in German]
(Accessed on 25 October 2022)

[6] **Coenradie, B.; Haag, L., Damm, A.; Kleinschmit, B.; Hostert, P. (2007):**
Hauptstudie "Entwicklung und Umsetzung eines hybriden Verfahrensansatzes zur Versiegelungskartierung in Berlin" [Main study „Designing and implementing a hybrid approach to mapping impervious coverage in Berlin"]. Final report. Senate Department for Urban Development (ed.).
Internet:
https://www.berlin.de/umweltatlas/_assets/literatur/ab_versiegelung_2007.pdf [only in German]
(Accessed on 9 December 2022)

[7] **Coenradie, B.; Haag, L. (2016a):**
Erhebung und Aufbereitung von Informationen zum Gründachbestand in Berlin [Collecting and processing information on Berlin's green roof inventory]. Final report. Senate Department for Urban Development and the Environment (ed.).
Internet:
https://www.berlin.de/umweltatlas/_assets/literatur/ab_versiegelung_2016.pdf [only in German]
(Accessed on 9 December 2022)

[8] **Coenradie, B.; Haag, L. (2016b):**
Versiegelungskartierung Berlin - Anwendung und Weiterentwicklung des hybriden Auswertungsverfahrens für das Jahr 2016 sowie Kartierung von Veränderungen [Mapping of impervious coverage in Berlin - Applying and refining the hybrid evaluation approach for the year 2016 including the mapping of changes]. Final report. Senate Department for Urban Development and the Environment (ed.).
Internet:
https://www.berlin.de/umweltatlas/_assets/literatur/ab_versiegelung_2016.pdf
(Accessed on 28 November 2022)

[9] **Coenradie, B.; Pauligk, A.; Fienitz, M. (2021):**
Versiegelungskartierung Berlin – Anwendung und Weiterentwicklung des hybriden Auswertungsverfahrens für das Jahr 2021 sowie Kartierung von Veränderungen. [Mapping of impervious coverage in Berlin - Applying and refining the hybrid evaluation approach for the year 2021 including the mapping of changes]. Final report. Senate Department for Urban Development Building and Housing (ed.).
Internet:
https://www.berlin.de/umweltatlas/_assets/literatur/ab_versiegelung_2021.pdf [only in German]
(Accessed on 19 December 2022)

[10] **DBU (Deutsche Bundesstiftung Umwelt [German Federal Environmental Foundation]) (2011):**
Leitfaden Dachbegrünung für Kommunen -Nutzen, Fördermöglichkeiten, Praxisbeispiele- [Green roof guide for municipalities – benefits, funding options, examples from practice]. Final report, October 2011.

Internet:
https://cms.dbu.de/media/29071409182171pn.pdf [only in German]
(Accessed on 15 May 2023)

[11] DDV (Deutscher Dachgärtner Verband e. V. [German Association of Roof Gardeners]) (2016):
Kommunale Gründach-Strategien Inventarisierung, Potenzialanalyse, Praxisbeispiele [Municipal green roof strategies; inventory, analysis of potential, examples from practice].
Internet:
https://digital.zlb.de/viewer/api/v1/records/16079949/files/images/DDV_Kommunale_Gruendach_Strategien.pdf/full.pdf [only in German]
(Accessed on 28 November 2022)

[12] Kattenborn, T., Leitloff, J., Schiefer, F., & Hinz, S. (2021):
Review on Convolutional Neural Networks (CNN) in vegetation remote sensing. ISPRS Journal of Photogrammetry and Remote Sensing, 173, pp. 24-49.
Internet:
https://www.researchgate.net/publication/348559309_Review_on_Convolutional_Neural_Networks_CNN_in_Vegetation_Remote_Sensing.
(Accessed on 19 December 2022)

[13] Pauligk, A; Stöckigt, B. (2022):
Erhebung und Aufbereitung von Informationen zum Gründachbestand in Berlin. [Collection and processing of information on Berlin's green roof inventory] Final report. Senate Department for Urban Development and the Environment (ed.).
Internet:
https://www.berlin.de/umweltatlas/_assets/literatur/ab_versiegelung_2021.pdf
(Accessed on 19 December 2022)

[14] Reichmann, B. (2009):
Stadtökologische Modellvorhaben und Gebäudebegrünung [Model projects in urban ecology and greening of buildings]. In: Tagungsband - Internationaler Gründach-Kongress 2009 “Dachbegrünung in der modernen Städtearchitektur” (Proceedings - International Green Roof Congress 2009 “Green roofs - bringing nature back to town”), pp. 135-144.

[15] Ronneberger, O., Fischer, P., Brox, T., (2015):
U-net: Convolutional networks for biomedical image segmentation. In: International Conference on Medical image computing and computer-assisted intervention, pp. 234–241. https://doi.org/10.1007/978-3-319-24574-4_28 (cit. on pp. 5, 26, 38).
Internet:
https://arxiv.org/pdf/1505.04597.pdf
(Accessed on 9 December 2022)

[16] SenJust (Senate Department for Justice and Consumer Protection) (2016):
Verordnung über die Erlaubnisfreiheit für das schadlose Versickern von Niederschlagswasser (NWFreiV) (Niederschlagswasserfreistellungsverordnung [Ordinance on the exemption from permits for the safe percolation of precipitation water - Precipitation water exemption ordinance, – NWFreiV] from August 24, 2001.last amended by Articles 1 to 4 of the law from April 28, 2016 (Federal Law Gazette I. p. 248).
Internet:
http://gesetze.berlin.de/jportal/portal/t/ys6/page/bsbeprod.psml?pid=Dokumentanzeige&showdoccase=1&js_peid=Trefferliste&documentnumber=1&numberofresults=1&fromdoctodoc=yes&doc.id=jlr-NiedSchlWasVBEpELS&doc.part=X&doc.price=0.0#focuspoint [only in German]
(Accessed on 28 November 2022)

[17] SenStadt (Senate Department for Urban Development) (2010):
Konzepte der Regenwasserbewirtschaftung . Gebäudebegrünung, Gebäudekühlung [Rainwater management concepts, Greening buildings, cooling buildings]. Leitfaden für Planung, Bau, Betrieb und Wartung [Planning, construction, operation and maintenance guidelines].
Download:
http://www.gebaeudekuehlung.de/SenStadt_Regenwasser_dt.pdf [only in German]
(Accessed on 28 November 2022)

[18] SenStadtUm (Senate Department for Urban Development and the Environment) (2016):
Anpassung an die Folgen des Klimawandels in Berlin – AFOK [Adaptation to the impacts of climate change in Berlin].
Internet:
https://www.berlin.de/sen/uvk/klimaschutz/anpassung-an-den-klimawandel/programm-zur-anpassung-an-die-folgen-des-klimawandels/ [German]
https://www.berlin.de/sen/uvk/_assets/klimaschutz/anpassung-an-den-klimawandel/programm-zur-anpassung-an-die-folgen-des-klimawandels/afok_summary.pdf [English summary]
(Accessed on 28 November 2022)

[19] SenStadtUm (Senate Department for Urban Development and the Environment) (2016a):
StEP Klima KONKRET – Klimaanpassung in der wachsenden Stadt [Urban development plan Climate 'CONCRETE' – climate adaptation in the growing city]
Internet:
https://www.stadtentwicklung.berlin.de/planen/stadtentwicklungsplanung/de/klima/index.shtml [only in German]
(Accessed on 28 November 2022)

[20] SenSW (Senate Department for Urban Development and Housing) (2017a):
Ökologisches Bauen - Modellvorhaben, Projekte [Ecological building - model concepts, projects]. KURAS "Konzepte für urbane Regenwasserbewirtschaftung und Abwassersysteme" ["Concepts for urban rainwater management and wastewater systems"].
Internet:
http://www.stadtentwicklung.berlin.de/bauen/oekologisches_bauen/de/modellvorhaben/kuras/index.shtml [only in German]
(Accessed on 28 November 2022)

[21] SenSW (Senate Department for Urban Development and Housing) (2017b):
Nachhaltiges Bauen. Ökologisches Bauen / Ökologische Gebäudekonzepte [Sustainable building; Ecological building / Ecological building concepts].
Internet:
http://www.stadtentwicklung.berlin.de/bauen/oekologisches_bauen/index.shtml [only in German]
(Accessed on 28 November 2022)

[22] SenSW (Senate Department for Urban Development and Housing) (2017c):
Ökologisches Bauen - Ökologische Gesamtkonzepte / Ökologische Bausteine [Ecological building - Ecological master plans / Ecological building blocks]. Baustein Grün ["Green" building block].
Internet:
http://www.stadtentwicklung.berlin.de/bauen/oekologisches_bauen/de/bausteine/gruen.shtml [only in German]
(Accessed on 28 November 2022)

[23] SenSW (Senate Department for Urban Development and Housing) (2019):
Ökologische Kriterien für Bauwettbewerbe [Ecological criteria for construction competitions].
Internet:
https://www.stadtentwicklung.berlin.de/bauen/oekologisches_bauen/download/bausteine/oekologische_kriterien_0907201966.pdf [only in German]
(Accessed on 9 December 2022)

[24] SenUVK (Senate Department for the Environment, Transport and Climate Protection) (2019):
Förderrichtlinie zum Programm „1.000 grüne Dächer" [Funding guidelines for the "1,000 Green Roofs" programme].
Internet:
https://www.ibb-business-team.de/fileadmin/ibb-business-team/gruendachplus/downloads/gruendachplus-richtline-des-landes-berlin.pdf [only in German]
(Accessed on 25 October 2022)

[25] SenUVK (Senate Department for the Environment, Urban Mobility, Consumer Protection and Climate Action) (2021):
Der Biotopflächenfaktor – Ihr ökologisches Planungsinstrument [The biotope area factor – your ecological planning tool].
Internet:

https://www.berlin.de/sen/uvk/_assets/natur-gruen/landschaftsplanung/bff-biotopflaechenfaktor/broschuere_bff_als_oekologisches_planungsinstrument.pdf [only in German]
(Accessed on 25 October 2022)

Maps

[26] SenSBW (Senate Department for Urban Development, Building and Housing Berlin) (ed.) 2022:
ALKIS Berlin (Amtliches Liegenschaftskatasterinformationssystem), Stand 05.2022.
Internet:
https://fbinter.stadt-berlin.de/fb/index.jsp?loginkey=showMap&mapId=wmsk_alkis@senstadt

[27] SenSW (Senate Department for Urban Development and Housing Berlin) (ed.) 2020a:
Digitale farbige TrueOrthophotos 2020 (TrueDOP2020RGB) – Sommerbefliegung [Digital colour true orthophotos, 2020 (TrueDOP2020RGB) – aerial photography flight in summer].
Internet:
https://fbinter.stadt-berlin.de/fb/index.jsp?loginkey=showMap&mapId=k_luftbild2020_true_rgb@senstadt [only in German]

[28] SenSW (Senate Department for Urban Development and Housing Berlin) (ed.) 2020b:
Geoportal Berlin / DOM - Digitales Oberflächenmodell 2020 [Berlin Geoportal / DSM – Digital Surface model, 2020].
Internet:
https://fbinter.stadt-berlin.de/fb/index.jsp?loginkey=showMap&mapId=k_dom1@senstadt [only in German]

[29] SenSW (Senate Department for Urban Development and Housing Berlin) (ed.) 2020b:
Geoportal Berlin / Informationssystem Stadt und Umwelt (ISU5) – Raumbezug [Berlin Geoportal, Urban and Environmental Information System (ISU5) – Spatial Reference].
Internet:
https://fbinter.stadt-berlin.de/fb/index.jsp?loginkey=showMap&mapId=k_isu5_2020@senstadt [only in German]

[30] SenSW (Senate Department for Urban Development and Housing Berlin) (ed.) 2020c:
Environmental Atlas Berlin, Map 06.10.02 Vegetation Heights, as of 2020, Berlin.
Internet:
https://www.berlin.de/umweltatlas/en/biotopes/vegetation-heights/2020/summary/

[31] SenSW (Senate Department for Urban Development and Housing Berlin) (ed.) 2020d:
Environmental Atlas Berlin, Maps 06.07 Urban Structure / 06.08 Urban Structure - Area Types Differentiated, 1 : 50.000, Berlin.
Internet:
https://www.berlin.de/umweltatlas/en/land-use/urban-structure/2020/summary/

[32] SenSW (Senate Department for Urban Development and Housing Berlin) (ed.) 2021a:
Geoportal Berlin / DGM - Digitales Geländemodell 2021 [Berlin Geoportal / DTM – Digital Terrain Model, 2021].
Internet:
https://fbinter.stadt-berlin.de/fb/index.jsp?loginkey=showMap&mapId=k_dgm1@senstadt [only in German]

[33] SenSW (Senate Department for Urban Development and Housing Berlin) (ed.) 2021b:
Digitale farbige TrueOrthophotos 2021 (TrueDOP2020RGB) – Bildflug vom 22.02.2021 [Digital colour true orthophotos, 2020 (TrueDOP2020RGB) – aerial photography flight of 22 February 2021].
Internet:
https://fbinter.stadt-berlin.de/fb/index.jsp?loginkey=showMap&mapId=k_luftbild2021_rgb@senstadt [only in German]