06.11 Green Roofs (Edition 2017)

Overview

Due to their positive ecological functions, green roofs contribute to reducing the impairment of the ecosystem in metropolitan areas. They reduce rainwater runoff, create evaporation surfaces and may increase biological diversity. Due to the possibility of creating additional greened areas where people can stay or engage in activities, they contribute to improving the urban residential environment.

Roof greening measures, as an element of greening both new buildings and the building stock, aim to achieve **relief of the sewer system, improvements in air hygiene, cooling effects on the urban climate** as well as strengthening species diversity. Greening buildings has further positive effects in that it reduces the noise level and enriches the cityscape. All these effects also contribute to promoting the health of the urban population with a view 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 in its current “Green Paper Urban Green” emphasises the role of greening roofs and facades for the health of the urban population (BMUB 2015).

Roof greening as an element of rainwater management can reduce problems of the sealed city such as urban heat islands and decrease the load of the surface waters (SenStadtWohn 2017a). Planted roofs lead to improved rain retention. The reduction in rainwater runoff relieves the sewer system (SenStadt 2010).

Since 2000, the charges for domestic wastewater and precipitation water are being billed separately in Berlin. In determining the sealed surfaces as a basis for the charges for draining the precipitation water, it is taken into account that surfaces that have little or no influence on the precipitation water runoff are not or only partially considered in the calculation of the fee for precipitation water disposal. For instance, for greened roof areas only 50 % of the respective area is considered in calculating the precipitation water fee (SenJust 2016, BWB n.d.).

Greening roof and facade surfaces has a long tradition in Berlin. At the beginning of the 19th century, there were already about 2,000 green roofs in Berlin, which were constructed as wood-cement roofs (Ahrendt 2007).

In West Berlin, a “courtyard greening programme” was initiated in 1983. The goal was primarily to reduce the green space deficits in the inner-city areas. The programme offered funding for measures for greening courtyards, greening facades and extensively greening roofs. East Berlin also had a courtyard greening programme in the 1980s. Beginning in 1990, the programme developed in 1983 was carried out in the entire inner-city area of Berlin, and advice on the preservation and maintenance of the facilities was provided. Over the course of the programme from 1983 to the end of 1995, 1,643 projects were approved, and 740,000 m² of courtyard and facade surfaces and 65,000 m² of roof areas were greened (Reichmann 2009).

Already in 1990, ecological requirements were defined in the guidelines on public funding for social housing, according to which resource conservation and environmental compatibility are to be taken into account. For example, vegetation concepts for greening facades and roofs as well as special ecological open space concepts and their implementation were eligible for funding.

Since 1992, ecological planning criteria are established for competitions in Berlin. They assert that “compensation measures in the form of roof gardens, roof and facade greenings make sense in particular in densely built-up inner-city areas […]" (SenStadt 2007). Greening roofs and facades is also an important component of building-related overall ecological concepts; outstanding projects in the area of green building in Berlin can be found here.

In the inner city, the “biotope area factor” (*Biotopflächenfaktor*, BFF) constitutes a particular form of ensuring “green qualities” to compensate deficits in free space and to reduce environmental loads. In

Berlin, the BFF can be prescribed by ordinance in a landscape plan. It designates the area proportion of a plot that serves as a plant site or assumes functions for the ecosystem, and thus includes green roofs (SenUVK n.d.).

The data that are now available on the stock of green roofs can be used for different purposes; they can form the basis for concepts of rainwater management in the urban space and likewise for continuous monitoring of the further development.

Moreover, the available inventory of green roofs can also be used for a future greened roof strategy. A determination of the further potential for green roofs in the city would be an important supplement for this purpose.

Statistical Base

Multispectral remote sensing data are particularly suitable for acquiring data on green roofs. The "view from above" allows a spectral differentiation of types and materials of surface covers of roofs. The essential statistical foundations for a precise assignment were given with the availability of up-to-date high-resolution digital colour-infrared orthophotos on the one hand and building and roof outlines on the other.

The following information was used as a statistical base:

- Digital colour-infrared orthophotos 2016 (DOP20CIR) from April 2 and 3, 2016 (SenStadtUm 2016c),
- Building and roof outline geometries as well as underground car parks without overlying buildings of the official property cadastre information system (*Amtliches Liegenschaftskatasterinformationssystem*, ALKIS) from April 2016,
- NOT-ALK buildings of the Environmental Atlas map "06.10 Building and Vegetation Heights (Edition 2014)" with data as of August 2009 and September 2010 (SenStadtUm 2014).

To minimise mapping errors, the following specialist planning data and geodata with citywide availability were further included:

- Blocks and block segments of the Urban and Environmental Information System at a scale of 1 : 5,000 (ISU5), including the uses available there (52 area types) from the Environmental Atlas map "06.08 Urban Structure - differentiated (Edition 2016)" as of December 31, 2015 (SenStadtUm 2016b),
- Data set building storeys in the Geoportal Berlin with data as of April 2016 (SenStadtUm 2016d),
- Vegetation height layers of the Environmental Atlas map "06.10 Building and Vegetation Heights (Edition 2014)" with data as of August 2009 and September 2010 (SenStadtUm 2014).

Methodology

The method that was developed for acquiring data on green roofs with the available statistical bases consists of two work steps:

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

The following diagram shows the procedure in detail. A correspondingly detailed description of the procedure can be found in the final report (Coenradie & Haag 2016a).

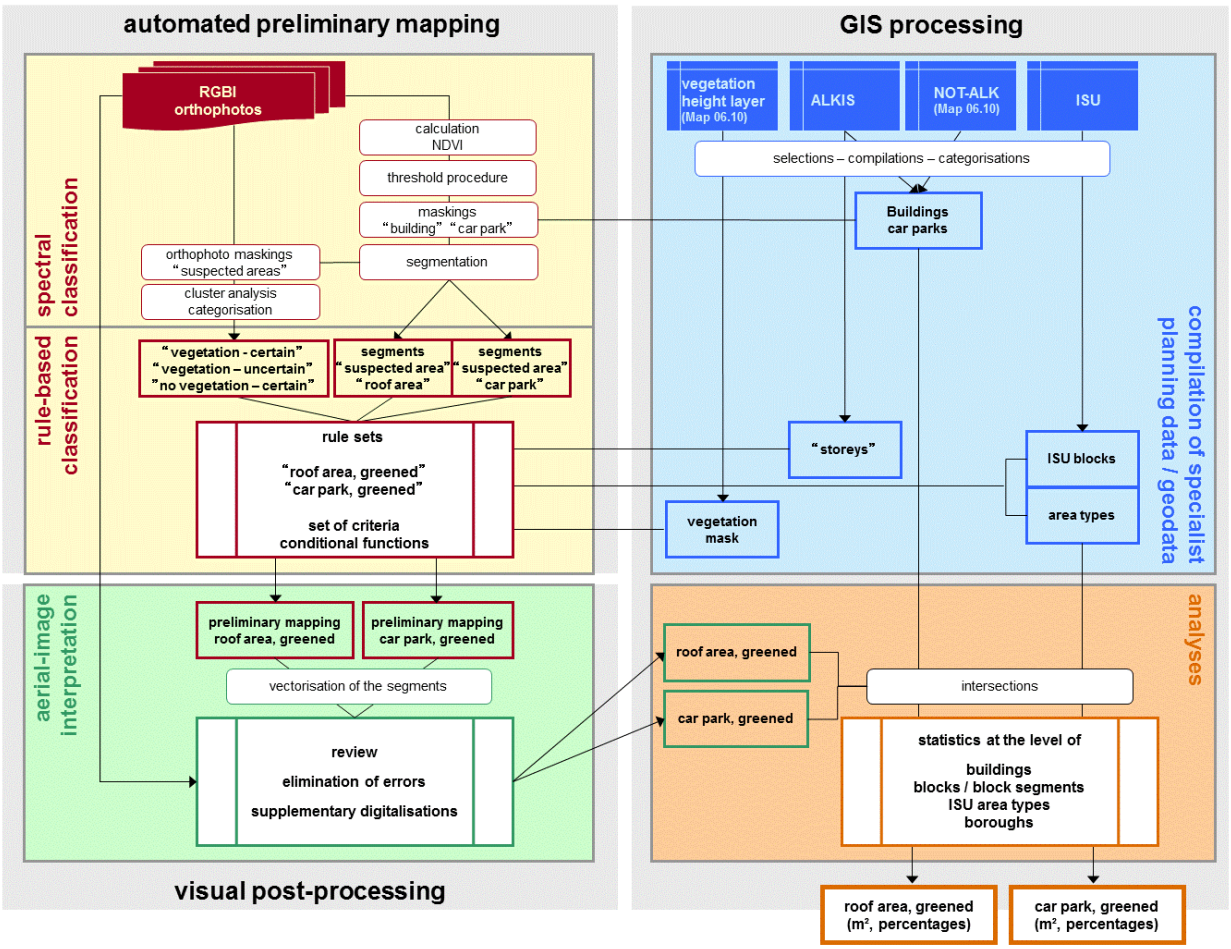

Fig. 1: Procedure diagram - data acquisition for the stock of green roofs of the State of Berlin

Automated preliminary mapping

In the course of the automated preliminary mapping, the object class "vegetation" should be recorded as precisely as possible within the building outlines. A combination of a spectral classification of the orthophotos using the **Normalized Difference Vegetation Index (NDVI)** and an unsupervised classification as well as a rule-based classification with inclusion of specialist planning data and geodata proved to be a suitable approach. The outlines of buildings and underground car parks formed the area of analysis, i.e. the search for vegetation was restricted to these outlines. Buildings that were not present in the statistical bases (ALKIS, NOT-ALK) were not analysed.

The NDVI is a synthetic channel that combines information from the near infrared (NIR channel) and the red spectral region (red channel), which causes vegetation areas to be particularly highlighted. In numerous investigations, this additional channel has proved successful in differentiating surfaces with and without vegetation cover as well as classifying degrees of sealing (Coenradie et al. 2007, Coenradie & Haag 2016b). The vegetation index was also used to identify green roofs in a comparable project for several other cities (Ansel et al. 2015). In the green roof mapping for Berlin, the NDVI served for an initial coarse delimitation of vegetation on roofs. Corresponding segments were subsequently more finely differentiated with an unsupervised classification procedure (ISODATA cluster analysis). The distribution of the spectral data was analysed automatically, and statistical clusters and spectrally similar image points were identified and combined into 100 spectral classes. These clusters were subsequently assigned to the categories "vegetation, certain", "vegetation, uncertain" and "no vegetation, certain".

Finally, a rule-based classification of the vegetation segments was carried out. For this purpose, the spectral mappings were merged with selected specialist planning data and geodata in a rule set. This allowed mapping errors to be considerably reduced.

In particular, **including the area types** (Environmental Atlas map Urban Structure - area types differentiated (06.08)) in the rule set allowed a spatially differentiated classification of Berlin to be carried out. Thus, for example, it is to be expected that buildings are obscured to a considerable extent in the thoroughly greened parts of the city (including “Village-like mixed development (21)” or “Villas and town villas with park-like gardens (24)”) or in “Allotment gardens (37)”. In areas with new buildings (“Multi-storey residential development since the 1990s (73)”), buildings are hardly ever obscured by treetops. Tilting of buildings is mainly concentrated in areas of the type “Large estates and single-tower high-rise buildings (9)”. The rule set was adapted accordingly for a selection of area types, which allowed the mapping in these areas to be improved.

The result was a classification of the roof area into the categories “vegetation” and “no vegetation”. Based on the spectral reflection properties, the vegetation segments were further subdivided into intensive and extensive greening components (cf. Figure 2). In this context, strongly vegetated areas with vital vegetation count as intensively greened areas. Extensively greened areas exhibit weaker or possibly drier vegetation.

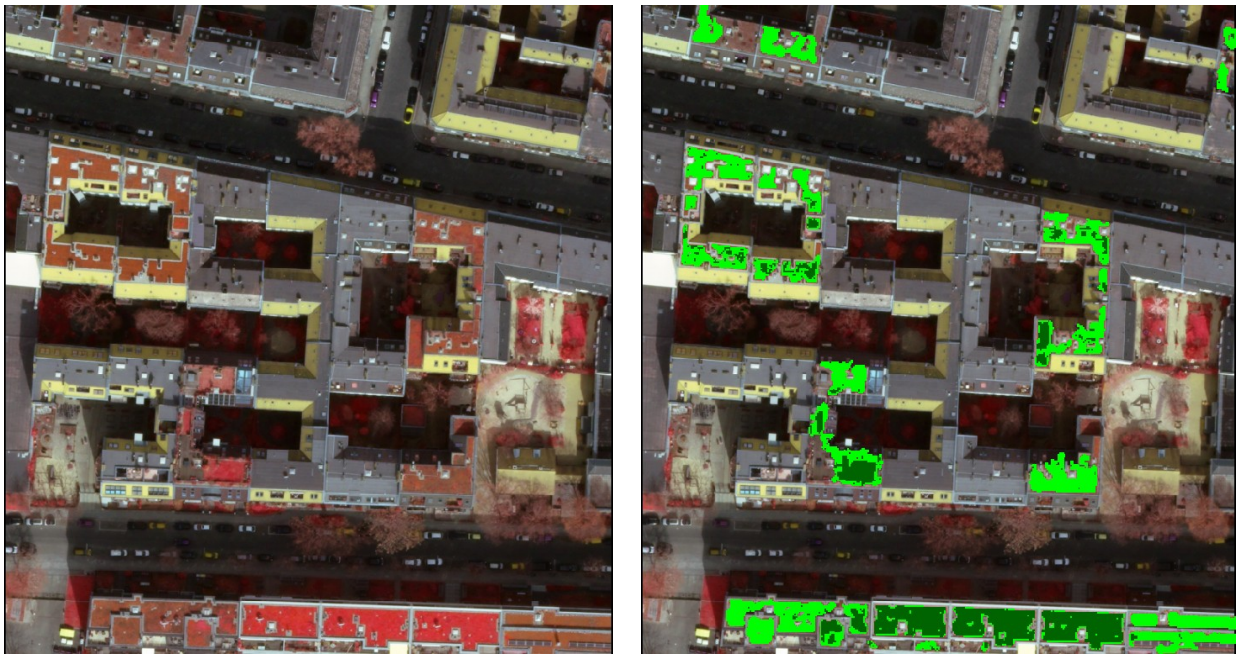

Fig. 2: Results of the automated preliminary mapping (dark green: intensively greened, light green: extensively greened)

Visual post-processing

The intermediate results of the automated preliminary mapping were reviewed and improved by means of interpreting aerial images.

The rules of interpretation were as follows:

- All vegetated roof areas count as green roofs, independent of whether they were established 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.
- The review focuses mainly on the areas identified by the preliminary mapping; large missing green roofs are additionally digitised if they are spotted.

- A greened roof is considered to be captured if more than two thirds of it is mapped by the preliminary mapping. No additional digitisation occurs in this case. Green roofs of which less than two thirds have been captured are subjected to additional digitisation.
- If shading or covering by trees (this mainly affects garage roofs) prevents the greened roof from being recognised, an existing preliminary mapping is removed.

Upon completion of the review of the areas, those greened roof areas were selected that occupied an area > 10 m² per building. Smaller mapped areas were removed.

Linking to further geodata allowed the following result layers to be created, which are also shown in the Geoportal:

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

Map Description

In Berlin, 18,368 (3.0 %) out of a total of 604,865 buildings, including underground car parks without overlying buildings, have a greened roof area or greened partial roof areas of > 10 m². In total, 400 ha of the roof areas are greened (3.9 %) (Table 1). A look at the map reveals a concentration of greened roof areas in Berlin's inner city.

Tab. 1: Greened roof areas in Berlin

	Number of buildings		Greened roof area				Floor area of the buildings	
			intensive		extensive			
		%	m²	%	m²	%	m²	%
Greened roof area present	18,368	3.0	605,507	0.6	3,397,176	3.3	11,847,832	11.5
Total Berlin	604,865		4,002,682 / 3.9				103,299,727	

Tab. 1: Greened roof areas in Berlin

The categorisation per building as "intensively" or "extensively greened" is carried out based on the predominant component. If a building exhibits a greened roof area of >50 % "extensive", the entire greened roof area enters into the calculations as "extensive".

Analyses on three spatial levels will be shown in the following – building, block and block segment of the ISU and borough.

Building

The buildings were classified into six categories of building use based on the ALKIS and NOT-ALK use. Table 2 and Figure 3 show the order of magnitude and percentages of the building uses covered with green roofs.

The greened roof areas [m²] are relatively evenly distributed across the different building uses "Residential" (including weekend cottages), "Non-residential buildings" (e.g. schools, town halls, retirement homes, administrative buildings), "Office buildings, commercial" and "Underground car parks without overlying buildings" with percentages between 20 and 25 % (Fig. 3).

In addition, Table 2 indicates **possible potentials for future green roofs**. The building use **"Office buildings, commercial"**, which presumably has a high proportion of flat roofs, only has greened roof areas on 2.7 % of the buildings to date. A high potential for green roofs can be assumed here. By contrast,

this potential is much more intensely utilised at **80 % in the case of underground car parks**, as expected, albeit with different proportions of greening on the individual roof areas of greened underground car parks.

Tab. 2: Distribution of the greened roof areas by building use

Building use	Number of buildings with greened roof area						Number of buildings without greened roof area	Total number of buildings	Greened roof area [m²]			Building floor area [m²]	Share of the greened roof area in the building floor area [%]
	≤25*	>25-50*	>50-75*	>75*	total	total [%]			intensive	extensive	total		
Residential	2,757	2,510	1,731	623	7,621	2.5	302,862	310,483	67,165	868,163	935,328	53,696,405	1.7
Non-residential building	917	548	567	508	2,540	4.5	54,138	56,678	93,742	814,188	907,931	25,828,250	3.5
Office building, commercial	594	419	352	307	1,672	2.7	60,679	62,351	66,946	805,735	872,681	12,743,121	6.8
Underground car park without overlying buildings	451	592	924	945	2,912	80.4	710	3,622	348,388	684,898	1,033,286	2,234,502	46.2
Garage, shed	79	190	608	2,057	2,934	1.8	157,688	160,622	13,482	74,958	88,441	6,186,411	1.4
Miscellaneous	230	191	167	101	689	6.2	10,420	11,109	15,782	149,234	165,016	2,611,038	6.3
Total	**5,028**	**4,450**	**4,349**	**4,541**	**18,368**	**3.0**	**586,497**	**604,865**	**605,507**	**3,397,176**	**4,002,682**	**103,299,727**	**3.9**

Tab. 2: Distribution of the greened roof areas by building use (Share of the greened roof area in the building floor area [%])*

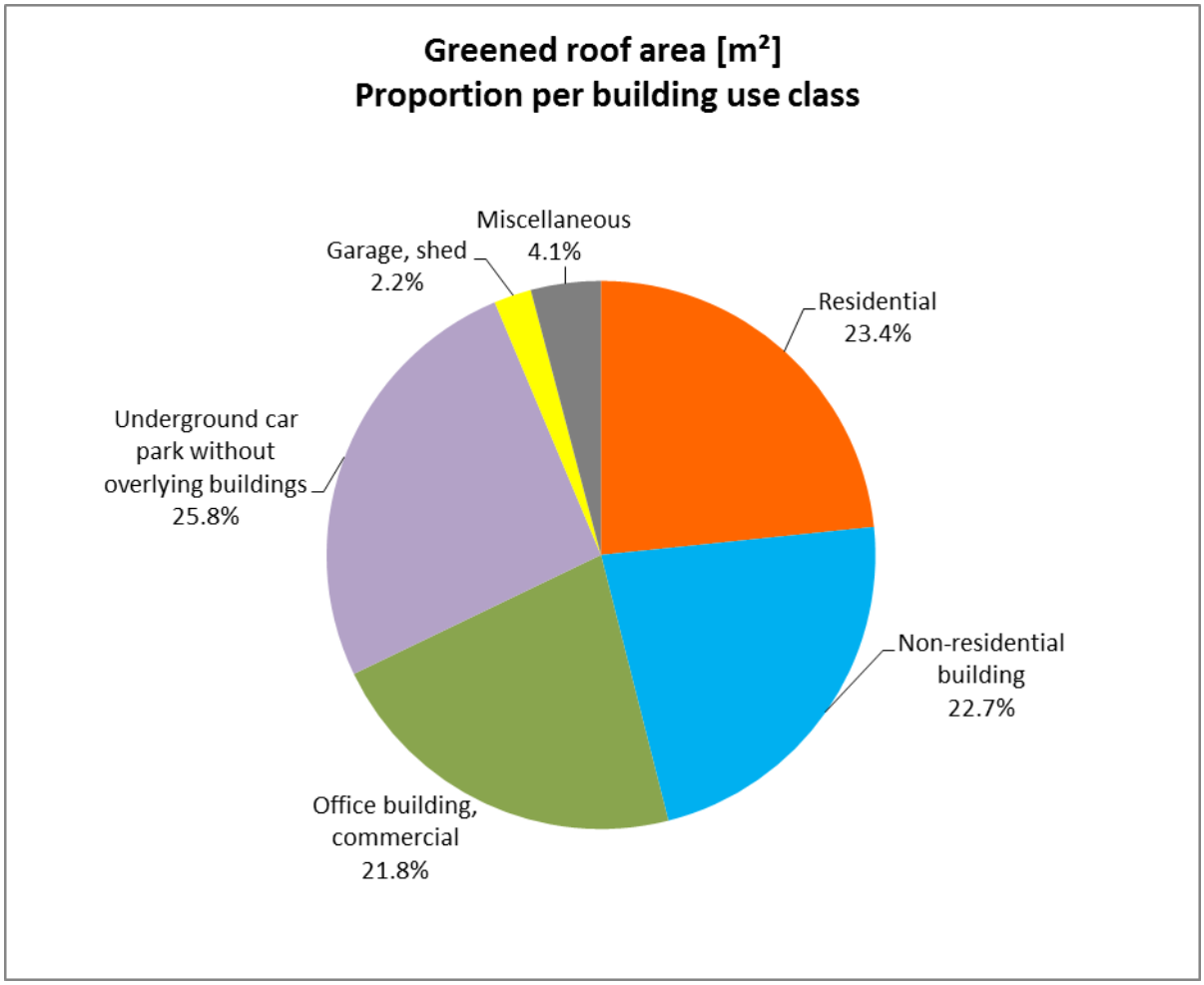

Fig. 3: Greened roof area [m²] - Proportion per building use class

Block and block segment

The assignment of the buildings to the block and block segment areas of the ISU also allows analyses to be carried out based on the area types available there (Table 3).

With a total of more than 30 ha each, the area types “Settlement from the 90s or later (73)”, “Commercial and industrial area, large-scale retail with sparse development (30)”, “Closed block development, rear courtyard, 5-storey (2)”, “Core area (29)” and “Closed and semi-open, de-cored block development, post-war gap closure (7)” exhibit the largest greened roof areas in absolute terms. Relative to the building floor area, the two area types “City square / promenade (54)” and “Settlement from the 90s or later (73)” stand out with a greened roof proportion of 31 and 22 % of the building floor area, respectively. However, as a further area type with a large building stock, the type “Detached single-family homes with yards (23)” merely exhibits a share of 1 % greened roof areas in the building floor area. This implies that there are principally greater potentials for green roofs in the private settlement area, which are, however, limited to the limited proportion of greenable roof constructions (flat or barely inclined roofs).

Tab. 3: Distribution of the greened roof areas by area type of the ISU										
Area type 2015		Number of buildings with green roof			Greened area [m²]			Total number of buildings	Total building floor area [m²]	Share of the greened roof area in the building floor area [%]
		intensive	extensive	total	intensive	extensive	total			
1	Dense block development, closed rear courtyard, 5 - 6-storey	41	307	348	6,280	36,270	42,550	4,588	1,659,262	2.6
2	Closed block development, rear courtyard, 5-storey	273	2,291	2,564	60,208	313,230	373,438	30,232	9,543,659	3.9
3	Closed and semi-open block development, decorative and garden courtyard, 4-storey	132	447	579	27,050	62,113	89,163	12,652	3,074,604	2.9
6	Mixed development, semi-open and open shed courtyard, 2-4-storey	25	144	169	2,419	13,450	15,869	5,087	712,638	2.2
7	Closed and semi-open, de-cored block development, post-war gap closure	157	1,008	1,165	61,023	254,200	315,224	11,627	3,889,505	8.1
8	Heterogeneous inner-city mixed development, post-war gap closure	52	305	357	19,513	87,816	107,329	2,746	1,052,079	10.2
9	Large estates and single-tower high-rise buildings, 4 – 11-storey	39	537	576	19,703	143,064	162,768	10,927	5,098,438	3.2
10	Block-edge development with large quadrangles, 3 – 5-storey	52	176	228	24,410	31,833	56,243	10,171	3,017,656	1.9
11	Row development with landscaped residential greenery, 3 – 6-storey	121	909	1,030	38,057	147,459	185,516	21,852	5,611,537	3.3
12	Old school (built before 1945)	7	91	98	1,118	16,719	17,837	1,870	845,365	2.1
13	New school (built after 1945)	29	271	300	10,144	108,045	118,189	3,448	2,170,706	5.4
16	Uncovered sports facilities	11	136	147	5,953	34,633	40,586	4,317	1,096,771	3.7
17	Covered sports facilities	8	31	39	10,489	34,792	45,281	265	322,171	14.1
21	Village-like mixed development	12	47	59	760	4,609	5,369	7,024	728,636	0.7
22	Row houses and duplexes with yards	105	1,039	1,144	10,312	49,525	59,837	50,703	3,350,881	1.8
23	Detached single-family homes with yards	439	2,163	2,602	36,149	129,028	165,176	230,519	16,585,278	1.0
24	Villas and rented villas with park-like gardens	223	681	904	29,685	50,619	80,304	27,358	3,050,089	2.6
25	Densification in single-family home areas, mixed development with yards and semi-private greening	118	415	533	20,336	47,788	68,125	15,940	2,037,603	3.3
27	Cemetery	5	62	67	492	9,626	10,118	1,145	150,741	6.7
29	Core area	51	510	561	27,334	289,457	316,791	2,683	2,759,347	11.5
30	Commercial and industrial area, large-scale retail with sparse development	67	802	869	42,521	451,389	493,909	20,125	12,729,967	3.9
31	Commercial and industrial area, large-scale retail with dense development	16	293	309	8,717	185,684	194,401	3,423	4,070,527	4.8
32	Utilities area	8	46	54	5,817	9,474	15,292	1,962	927,720	1.6
33	Mixed-use area, mostly crafts and small business, with sparse development	36	192	228	6,533	36,602	43,136	5,734	1,196,039	3.6
36	Tree nursery / horticulture	1	12	13	15	1,050	1,066	550	141,087	0.8
37	Allotment garden	6	44	50	932	2,847	3,778	61,725	3,065,557	0.1
38	Mixed-use area, mostly crafts and small business, with dense development	16	136	152	3,830	35,510	39,339	1,447	557,209	7.1
41	Security and order	7	64	71	5,679	13,614	19,293	1,601	889,079	2.2
43	Administrative	23	172	195	8,970	81,085	90,055	1,561	1,322,618	6.8
44	University and research	16	111	127	13,270	53,140	66,410	1,582	1,085,438	6.1
45	Culture	2	31	33	2,209	12,043	14,251	658	595,859	2.4
46	Hospital	15	173	188	10,052	80,198	90,250	2,115	1,447,590	6.2
47	Children's day care centre	3	51	54	984	10,532	11,516	854	341,495	3.4
49	Church	1	15	16	92	2,807	2,899	577	173,663	1.7
51	Other youth facilities	3	24	27	933	3,089	4,022	612	171,377	2.3
53	Park / green space	28	43	71	1,207	4,673	5,880	1,892	210,568	2.8
54	City square / promenade	1	2	3	4,185	1,883	6,068	73	19,777	30.7
55	Forest	0	24	24	0	979	979	1,443	130,127	0.8
56	Agriculture	0	2	2	0	66	66	155	16,611	0.4
57	Fallow area	0	13	13	0	1,837	1,837	801	106,563	1.7
58	Camping ground	0	2	2	0	160	160	113	8,220	2.0
59	Weekend cottages and allotment-garden-like areas	4	37	41	108	1,451	1,558	20,468	866,913	0.2
60	Miscellaneous and heterogeneous public facilities and special-use areas	9	88	97	1,931	27,055	28,986	2,011	1,022,465	2.8
72	Row development with architectural green strips, 3 – 5-storey	26	108	134	6,016	10,571	16,587	7,032	1,492,476	1.1
73	Settlement from the 90s or later	178	1,787	1,965	68,742	471,200	539,942	6,732	2,457,136	22.0
91	Parking area	32	51	83	670	11,325	11,994	488	105,569	11.4
92	Railway stations and railway grounds, without track area	1	9	10	177	8,706	8,883	897	582,299	1.5
93	Airport	1	10	11	266	1,398	1,664	154	172,766	1.0
94	Other traffic areas	0	12	12	0	5,233	5,233	510	308,180	1.7
98	Construction site	0	2	2	0	144	144	270	56,733	0.3
99	Track area	0	4	4	0	1,000	1,000	666	128,337	0.8
100	Water body	0	3	3	0	64	64	112	7,375	0.9
Buildings on roadways		2	33	35	215	6,093	6,308	1,368	135,420	4.7
Total		**2,402**	**15,966**	**18,368**	**605,507**	**3,397,176**	**4,002,682**	**604,865**	**103,299,727**	**3.9**

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

Borough

Figure 4 shows the greened roof area in square meters per borough disaggregated according to the greened proportion of roof area in percent classes. Mitte and Charlottenburg-Wilmersdorf have by far the largest stock of greened roof areas. However, with respect to the share of greened roof area in the available building floor space, Friedrichshain-Kreuzberg exhibits the highest value in comparison (Figure 5). This diagram, too, underscores yet again the concentration of greened roof areas in the inner city, which is also due to the large number of flat and Berlin-style roofs that predominate there (Betz 2010). Figure 6 illustrates the overall low proportions of intensively green roofs. However, the proportions of intensively and extensively greened roof areas fluctuate across the boroughs.

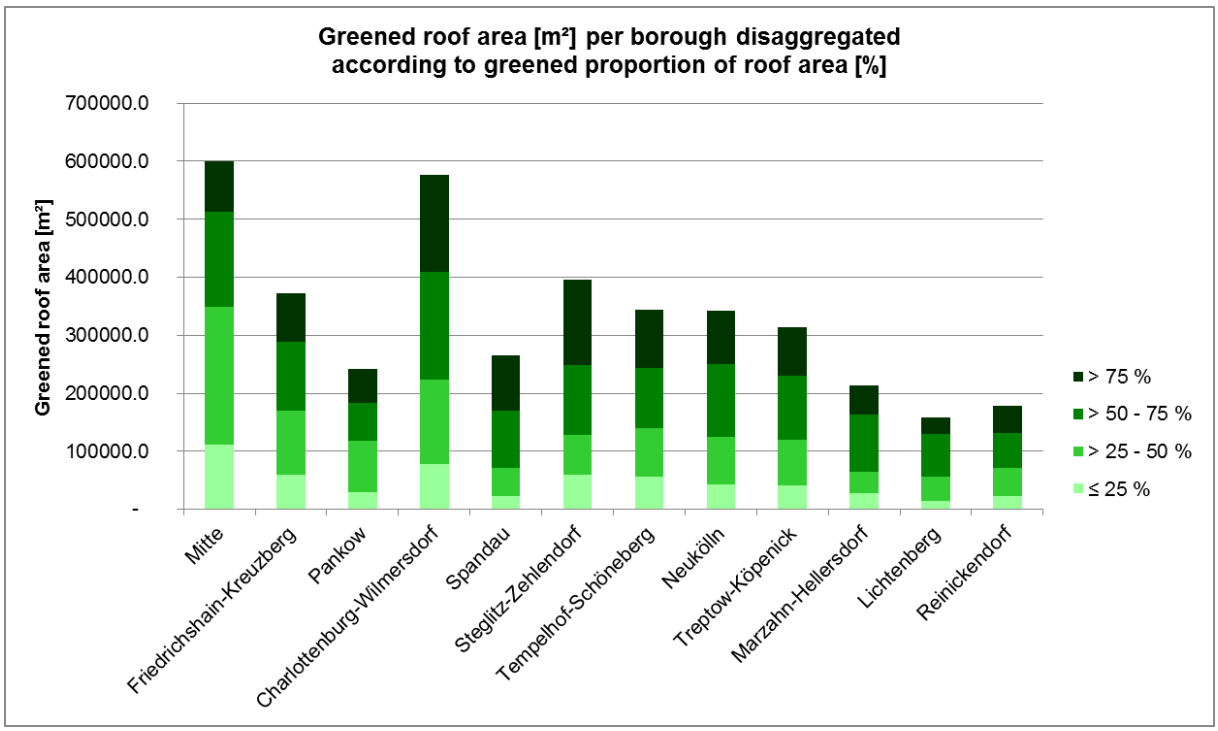

Fig. 4: Greened roof area [m²] per borough disaggregated according to the greened proportion of roof area [%]

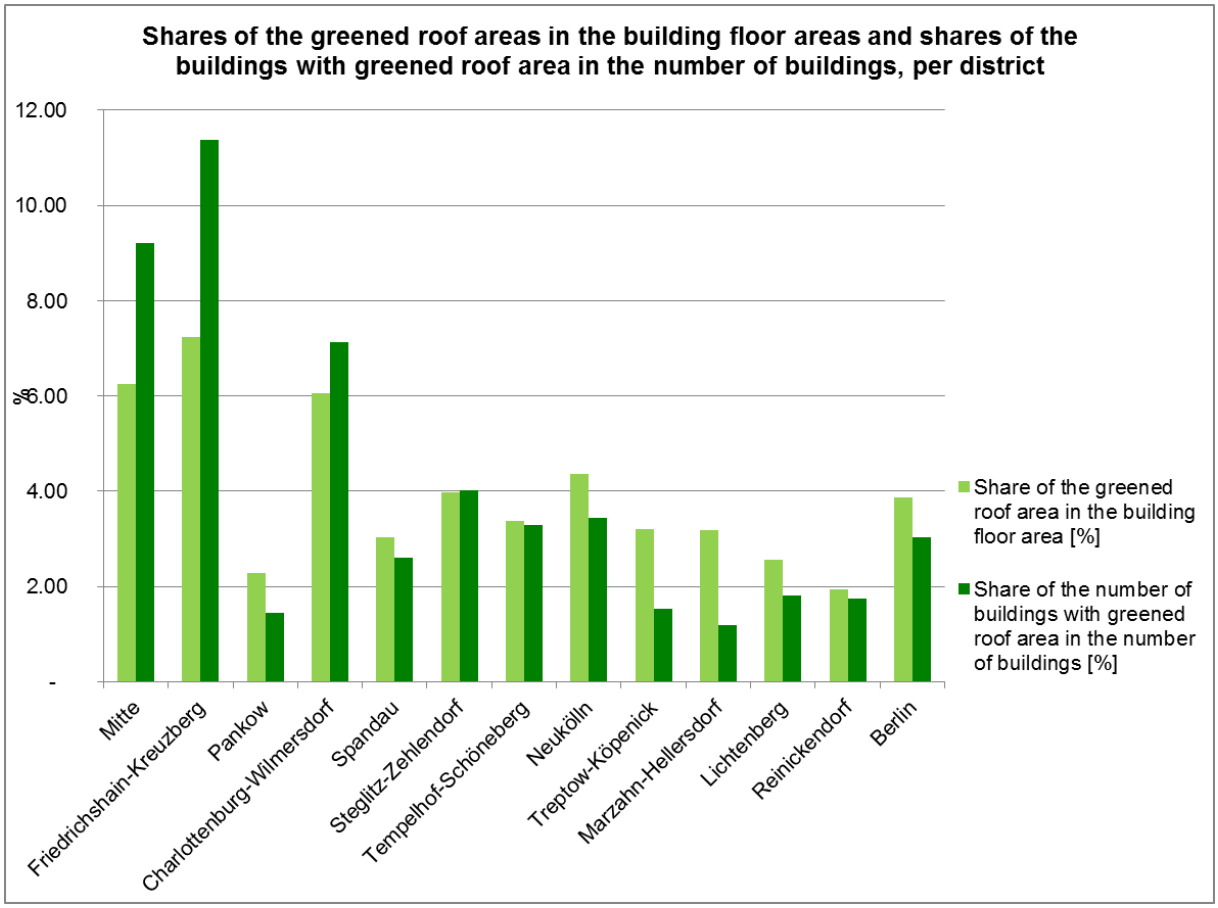

Fig. 5: Shares of the greened roof areas in the building floor areas and shares of the buildings with greened roof area in the number of buildings, per district

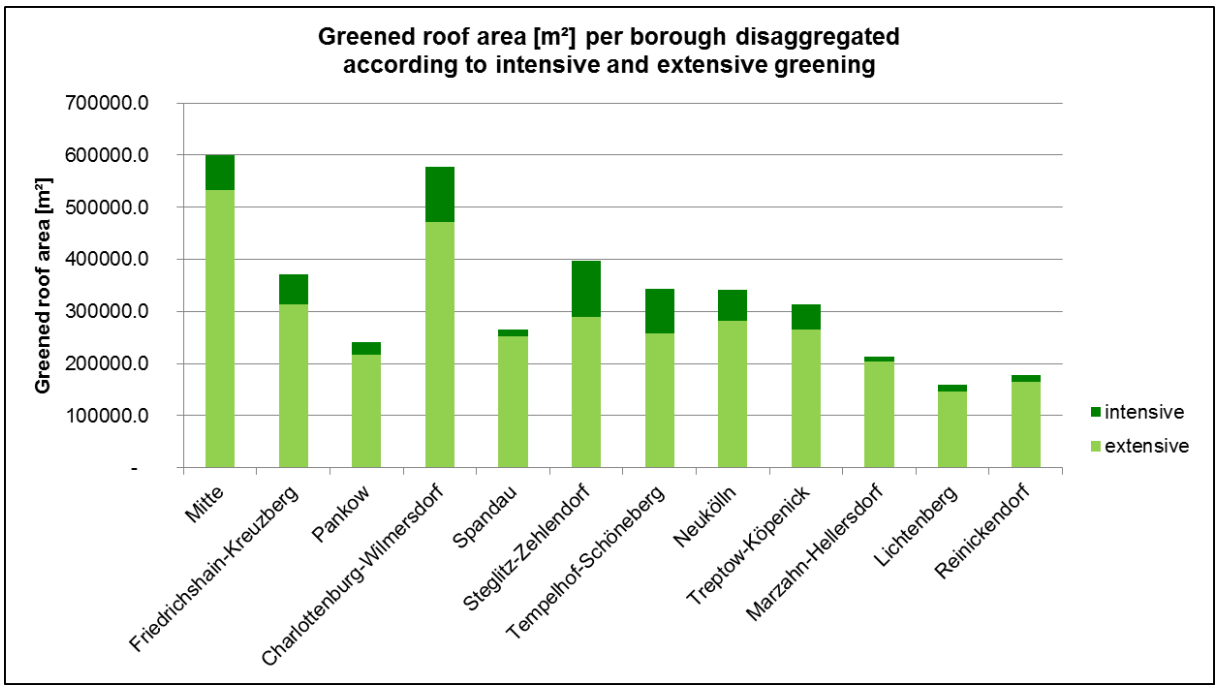

Fig. 6: Greened roof area [m²] per borough disaggregated according to intensive and extensive greening

Tab. 4: Distribution of the greened roof areas by borough

	Borough	Number of buildings with greened roof area					Greened roof area [m²]							Number of buildings	Building floor area [m²]	Share of the number of buildings with greened roof area in the number of buildings [%]	Share of the greened roof area in the building floor area [%]
		≤25*	>25-50*	>50-75*	>75*	Total	≤25*	>25-50*	>50-75*	>75*	intensive	extensive	Total				
1	Mitte	861	638	408	209	2,116	111,583	237,492	164,340	86,852	67,523	532,744	600,267	22,951	9,596,273	9.2	6.3
2	Friedrichshain-Kreuzberg	583	484	289	160	1,516	59,737	110,421	118,925	83,004	59,079	313,008	372,087	13,317	5,133,934	11.4	7.2
3	Pankow	395	320	257	147	1,119	29,721	88,123	65,567	58,438	24,045	217,804	241,849	76,895	10,563,956	1.5	2.3
4	Charlottenburg-Wilmersdorf	748	592	432	551	2,323	77,715	146,297	186,022	166,807	105,875	470,966	576,841	32,610	9,513,489	7.1	6.1
5	Spandau	296	305	408	716	1,725	23,620	48,185	97,452	96,489	13,851	251,895	265,746	66,427	8,731,389	2.6	3.0
6	Steglitz-Zehlendorf	464	579	715	933	2,691	58,921	69,653	120,570	147,350	106,228	290,266	396,494	66,850	9,993,332	4.0	4.0
7	Tempelhof-Schöneberg	522	367	368	410	1,667	56,970	83,041	104,040	99,178	84,636	258,593	343,229	50,715	10,145,263	3.3	3.4
8	Neukölln	411	395	455	470	1,731	42,345	82,677	125,912	90,766	58,708	282,991	341,699	50,311	7,815,695	3.4	4.4
9	Treptow-Köpenick	254	321	343	353	1,271	40,718	79,602	109,817	83,364	49,027	264,475	313,501	82,991	9,756,891	1.5	3.2
10	Marzahn-Hellersdorf	118	122	205	168	613	28,148	36,934	98,383	50,057	9,930	203,591	213,521	51,183	6,691,268	1.2	3.2
11	Lichtenberg	99	99	155	109	462	14,567	41,322	73,431	29,602	13,070	145,852	158,922	25,466	6,197,063	1.8	2.6
12	Reinickendorf	268	221	301	344	1,134	23,619	47,658	60,776	46,473	13,535	164,990	178,525	65,149	9,161,172	1.7	1.9
Total		**5,019**	**4,443**	**4,336**	**4,570**	**18,368**	**567,664**	**1,071,404**	**1,325,233**	**1,038,381**	**605,507**	**3,397,176**	**4,002,682**	**604,865**	**103,299,727**	**3.0**	**3.9**

Tab. 4: Distribution of the greened roof areas by borough (* Share of the greened roof area in the building floor area [%])

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