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6. NATURE-BASED SOLUTIONS FOR URBAN WATER MANAGEMENT: ANALYSIS OF HOUSING ESTATES IN GDAŃSK, GDYNIA, AND WARSAW

6.1. Introduction – living with nature

Rapid urbanization has highlighted the importance of optimalization of usage and management resources in buildings and their surroundings. One of the biggest, current trends in smart cities is management of storm water that is the common goal as well for adaptation and mitigation to the climate changes. IPCC rapports don't give much hope, the growth of the global temperature is a fact and should be expected[2]. The need for innovative and natural approach is big. The one based on natural-based solutions (NBS) is especially interesting, what is proved on international and European background. Firstly, it was defined by International Union for Conservation of Nature (IUCN) as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits"[3]. Second definition comes from European Commission and says that those solutions are „inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience."[4]. What's more NBS could have real impact on mitigation and provide 30% of cost-effective mitigation of climate change, that could help to keep to meet the Paris Agreement goal of limiting warming to below 2°C above preindustrial levels[5].

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[2] IPCC WGII Assessment Report, Climate Change 2022: Impacts, Adaptation and Vulnerability. Summary for Policymakers.

[3] IUCN global standards for nature-based solutions, https://www.iucn.org/theme/nature-based-solutions/resources /iucn-global-standard-nbs [access: April 2022].

[4] European Commission nature-based solutions, https://ec.europa.eu/info/research-and-innovation/research-area/environment/nature-based-solutions_en [access: April 2022].

[5] Griscom B.W., Adams J., Ellis P.W., Houghton R.A., Lomax G., Miteva D.A., Schlesinger W.H., Shoch D., Siikamäki J.V., Smith P., Woodbury P., Zganjar C., Blackman A., Campari J., Conant R.T., Delgado C., Elias P.,

NBS for addressing water management within cities among others include bioswales, retention and detention basins (or bioretention cells/filters), (constructed) wetlands, rain gardens, permeable pavements, riparian vegetation strips and green roofs[6]. Basic advantages consider protection and reducing surface runoff[7]. The effectiveness of NBS for urban water management depends on the type and design of the NBS and the local conditions. Small-scale NBS have been found to reduce run-off by 30–65 % for porous pavements, up to 100 % for rain gardens or up to 56 % for infiltration trenches[8]. In terms of mitigation various advantages are expected from NBS considering shaping optimal microclimate, reducing heat wave[9], and regulating thermal comfort[10]. Holistic approach is very important that is not only "nature-oriented" but as well "human-oriented"[11]. That means that NBS should provide benefits for people and biodiversity[12]. Researchers proved that blue and green infrastructure has positive impact on wellness, mental health[13] and reconnects people with nature[14].

Although knowledge about methods of rainwater management systems is increasing, the realizations not always achieved to replicate hydrological conditions of pre--development landscape[15]. Unfortunately, due to the IPCC report lots of adaptation

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[6] EEA Report, No. 01/2021, Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction.

[7] Wagner I., Zalewski M., Krauze K.: Błękitne aspekty zielonej infrastruktury. [In:] Zrównoważony rozwój – Zastosowania, 2013, No. 4, pp. 144–155; Januchta-Szostak A.: Modular water squares (MWS) in Poznań – people-friendly solutions for rainwater management, Journal of Sustainable Architecture and Civil Engineering, 2015, Vol. 3, No. 12, https://doi.org/10.5755/j01.sace.12.3.12659.

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[9] Prenner F., Müller H., Stern P., Holzer M., Rauch H.P., Kretschmer F.: Suitability pre-assessment for decoupling in-sewer captured streams to support urban blue and green climate adaptation measures, Journal of Water and Climate Change, 2022, Vol.13, No. 4, pp. 1748–1764, https://doi.org/10.2166/wcc.2022.458.

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[11] EEA Report, No. 01/2021, Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction; Kabisch N., Frantzeskaki N., Hansen R.: Principles for urban nature-based solutions, Ambio, 2022, Vol. 51, pp. 1388–1401, https://doi.org/10.1007/s13280-021-01685-w

[12] Kabisch N., Frantzeskaki N., Hansen R.: Principles for urban nature-based solutions, Ambio, 2022, Vol. 51, pp. 1388–1401, https://doi.org/10.1007/s13280-021-01685-w.

[13] Wuijts S., de Vries M., Zijlema W., Hin J., Elliott L.R., van Breemen L.D., Enrico Scoccimarro, Roda Husman A.M, Külvik M., Frydas I.S., Grellier J., Sarigiannis D., Taylor T., Gotti A., Nieuwenhuijsen M.J., Hilderink H.: The health potential of urban water: Future scenarios on local risks and opportunities, Cities, 2022, Vol. 125: 103639, https://doi.org/10.1016/j.cities.2022.103639; Liu H.Y., Jay M., Chen X.: The role of nature-based solutions for improving environmental quality, health and well-being, Sustainability, 2021, Vol. 13: 10950, https://doi.org/10.3390/su131910950.

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[15] Parris K.M., Amati M., Bekessy S.A., Dagenais D., Fryd O., Hahs A.K., Hes D., Imberger S.J., Livesley S.J., Marshall A.J., Rhodes J.R., Threlfall C.G., Tingley R., van der Ree R., Walsh Ch.J., Wilkerson M.L.,

projects leads in fact to the maladaptation and can have negative impact on the environment in long term perspective[16]. The concept of nature is both socially mediated and historically specific. The idealistic framing based on goodness, protectiveness of nature renders nature as a powerful political tool. It causes the risk of false implementations of unnatural solutions[17]. Greenery in an inseparable element of contemporary campaigns which promote new houses. Renderings and advertisements show much more greenery than if it had actually been planted later and most do not meet the NBS criteria[18].

The following research tries to verify whether trend of rainwater management on contemporary housing estates in Poland is present. Do proposed solutions meet NBS criteria and can be observed there increase of rainwater capacity?

6.2. Review method

The main goal of the research was to analyse contemporary housing estates in terms of nature-based solutions of rainwater management system (RMS). Three housing estates were selected in the cities that execute the Adaptation plans for climate changes. Due to the research goal, the main selection reason was the time of the housing's construction. All of the selected fragments of estates were planned, constructed and released in XXI century and are advertised by developer as sustainable or caring for ecosystems. Thus, the main question is how it is accomplished. Is it just a marketing or real design solutions?

Description of the RMS was divided into four stages.

In the first stage overall, evaluation of the area division into use was made. Additionally, green area was divided into more precise sections to better verify the efficiency of the RMS. The evaluation is based on surface inventory of the area during in-situ research.

Second stage was to verify the terrain profile. It is crucial for shaping the rainwater retention because, due to the gravitation water can be directed to the lower parts and

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additionally filtered. Diagrams are created using geoportal.gov. The terrain profile refers to the ground levels before buildings construction.

The third stage describes RMS for every estate. Considered RMS is defined as elements infiltrating, temporary retaining or infiltrating and temporary retaining rainwater that are connected together by the water flow. All of elements are composed from basic components parts. The crucial thing in system evaluation is to identify component parts and elements which are presented in two tables. First table is about identified component parts (i.e., surfaces, type of greenery, methods of water directing, irrigation methods). Second table shows typology of elements used in RMS. Elements and components were identified during in-situ research.

Fourth stage presents the typical element of the system. The working mechanism, including water sources, its flow and direction, is presented on the photographs. That is a base for further efficiency evaluation.

6.3. Green meridian housing estate (Gdańsk)

6.3.1. Description of the researched area

Housing estate is located in the southern part of the city Gdańsk in the suburbs, about 8 km away from the city center. It is close to the express road S7 that connects four Polish agglomerations: Tri-City, Warsaw, Kielce, and Krakow. In 2018 the construction has started. There are 13 building already put into use, 17 building are about to be put into use in April, 2022, and two buildings are being planned[19]. Buildings have three or four levels. There are designed on the ground car parking spaces.

The study covers the area of 39,000 m^2 It consists of 12 buildings, six parking areas, two playgrounds and one herbarium (Fig. 6.1). Communication infrastructure at the research fragment takes 34% and buildings 13% of a total area. Rest 53% stands for permeable areas which in details are open green areas (10%), private gardens (20%) and rainwater gardens with plants up to 1m height (70%) (Fig.6.2).

[19] https://korter.com.pl/zielony-poludnik-gdansk [access: April 2022].

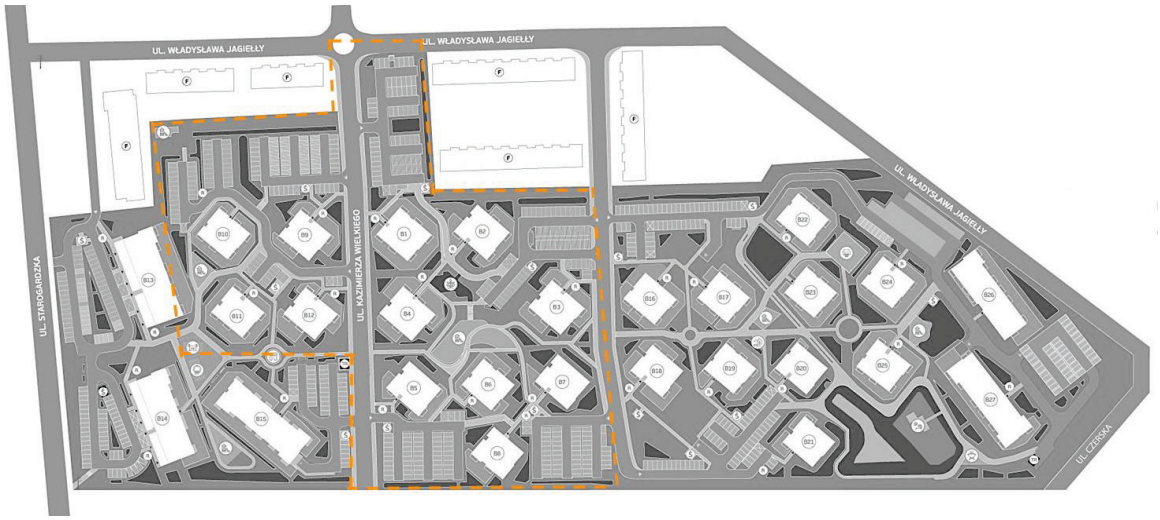


Fig. 6.1. Gdańsk, the plan of Green Meridian housing estate, chosen fragment
Rys. 6.1. Gdańsk, plan osiedla Zielony Południk, wybrany fragment
Source: https://www.eurostyl.com.pl/pl-pl/trojmiasto/lista-inwestycji/zielonypoludnik?city=trojmiasto.

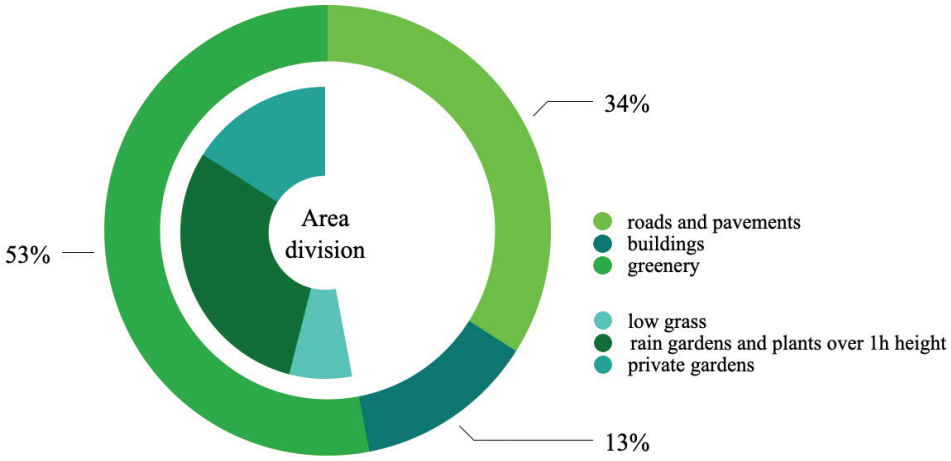


Fig. 6.2. Area division at Green Meridian housing estate
Rys. 6.2. Podział terenu na osiedlu Zielony Południk

6.3.2. Digital terrain model and terrain profile

The area of the housing estate is not plain what can be noticed on the digital terrain model (Fig. 6.3A). Darker colour stands for higher parts and lighter colour stands for lower parts. The terrain profile (Fig.3.3B) shows in detail how the topography of the research area looks like. Total length of measure is 583 m. The length of the sections up is 227 m. The length of the sections down is 356 m. Highest point is at 59 m and lowest at 44 m what gives 15 m of height difference.

Topography of the area took prime part in shape of RMS at the estate. The areas placed lower are used as surface retention elements and are the places for major raingardens.

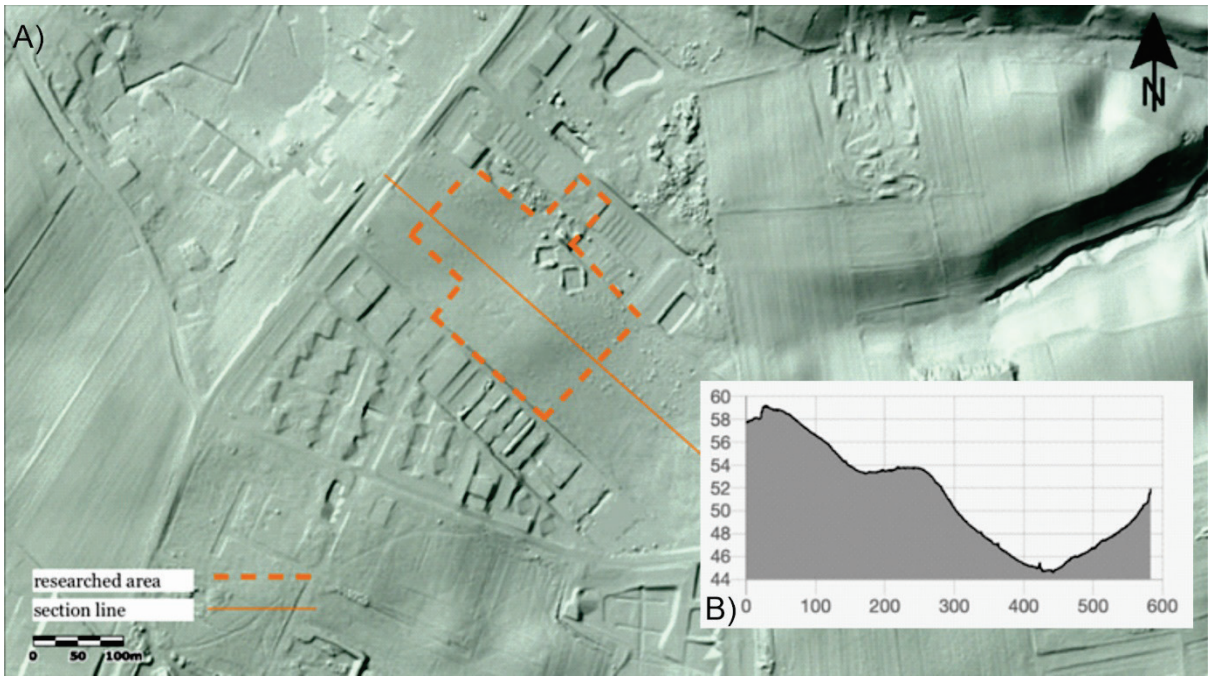


Fig. 6.3. Digital terrain model (A) with terrain profile (B), housing estate Green Meridian
Rys. 6.3. Numeryczny model terenu z przekrojem profilu, osiedle Zielony Południk
Source: geoportal.com

6.3.3. Rainwater system

The base elements of an RMS are raingardens in different sizes and shapes. They collect rainwater from the roofs of residential buildings and water from surface runoff from impermeable surfaces. Due to the high differences, rainwater by gravity is directed into bigger raingardens. The direction of water flow is manipulated by a system of open troughs and lowering curbs. The RMS component parts are different types of greenery i.e.: low grass, plants over 1 m and trees with crown diameter around 1.5 m. Majority of greenery, including trees, are very young that gives an impression of a little green space. In this case area of the parking, some roads, pavements and greenery excluding private gardens is the area of functioning RMS. Some of the roads has additional sewage overflow on the surface.

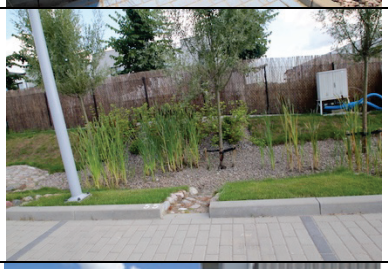
The table 6.1 shows recognized basic component parts of RMS.

Table 6.1

Component parts of the rainwater system

Category	Type	Picture, Foto PGM 2021
Greenery	Low grass	
	Greenery over 1m hight	
	Trees – crown diameter about 1.5 m	
Surfaces	Impermeable – jointless concrete bricks	
	Permeable – gravel, stones	
Method of directing the water	Hights differences	

continue table 6.1

Method of directing the water	Open channels	
	Gaps in the curbs	
Irrigation method	Rainwater from the roofs	
	Rainwater from the surface runoff	

Author's photography, 2021.

The following breakdown shows typology of elements of RMS (Table 6.2). Rainwater gardens in different shapes and forms are the base for the strategy for this system.

Table 6.2

Elements of rainwater system

S	A	Picture	Name and main goal	Description
SR	6		Small (< 2 m^2) raingarden - infiltration	Element collecting water from surface runoff from the pavement. A small cavity, lined with crushed stone, equipped with an emergency overflow above the cavity. Accompanying greenery.
BR	17		Big (> 2m^2) raingarden – temporary water basin - temporary retention of bigger amount of water	An element that collects water from surface runoff from pavements and roads. It functions as a temporary water reservoir during heavy rains. Troughs made of larger stones to direct the water. Emergency overflow above the depression. Accompanying greenery.
LR	3		Linear raingarden – temporary water basin - temporary retention	An element that collects water from the roofs of buildings and from the surface of impermeable pavements. It functions as a water reservoir during heavy rains. Emergency overflow above the depression. Accompanying greenery.

continue table 6.2

GN	6		Green niche – infiltration and short time retention	An element that collects water from the roofs of residential buildings and from the surface of impervious sidewalks. It functions as a temporary water reservoir during heavy rains. Emergency overflow above the depression. Accompanying greenery.
SB	9		Support basin – infiltration and temporary retention	Water directed by underground pipes from different areas. Filled with rain water during heavy rains. Bottom covered with layer of stones to increase infiltration and improve aesthetics. Collect overflow from other connected gardens.
LT	3		Linear trough	Water collected from the salad surface of the parking. Later directed with the underground pipe to the nearest rain garden.
LN	3		Linear niche – infiltration	Water collected from the roof. Niche filled with plants.

continue table 6.2

PR	5		Raingarden along parking – temporary retention	Niche collects water from the parking. Water is directed by open channel. Equipped with emergency overflow. Accompanying greenery.

Author's fotographies, 2021. S-symbol. A-amount.

6.3.4. Description of a typical solution

Rainwater garden is the RMS typical element (Fig. 3.4). The basin is located on the lower level what allows to collect the rainwater from higher parts. Water is directed by open channels and by gravity into desired basin. In this case, raingarden collects water from pavements, parking area, and roof. The bottom of the basin is filled with gravel, which improves the aesthetics of the tank after drying. Rain gardens are not green enough, which makes the gravel visible. In general, there seems to be few greeneries.

Fig. 6.4. Typical element of rainwater system at the Green Meridian housing estate – raingarden
Rys. 6.4. Typowy element system gospodarowania wodą deszczową na osiedlu Zielony Południk – ogród deszczowy
Source: author's photo, 2021.

There was no existing green, so the visible green is new plantings. It is necessary to repeat the research in the period of several years, when the greenery grows and fills the interior of the basin.

6.4. Beaufort's housing estate (Gdynia)

6.4.1. Description of the researched area

Housing estate is located in Gdynia, in the northern part of the city in the district Pogórze, about 9 km away from the city center. The construction of the estate started in 2017. Concept consists of 20 buildings with inner courtyards and recreational sport zone in the entrance of the concept, 16 buildings are put in use, 12 buildings are about to be put in use in 2022 and five buildings are still in the planning process[20]. Designed buildings are two or three levels tall. There are designed both underground and on the ground car parking spaces. The study covers the area of 47 700 m^2. It consists of skate park, sport pitch, 14 buildings, three playgrounds, herbarium and flower valley (Fig. 6.5). Roads and pavements account for 37%, buildings for 17% and permeable surfaces for 46% of the total researched area. Permeable surfaces are divided into low grass (10%), private gardens (17%) and raingardens and plats up to 1m (73%) (Fig. 6.6). It is worth to notice that due to the underground parking some of the plants grow on the flat roofs. It is estimated that majority of the greenery from the courtyards are above parking.

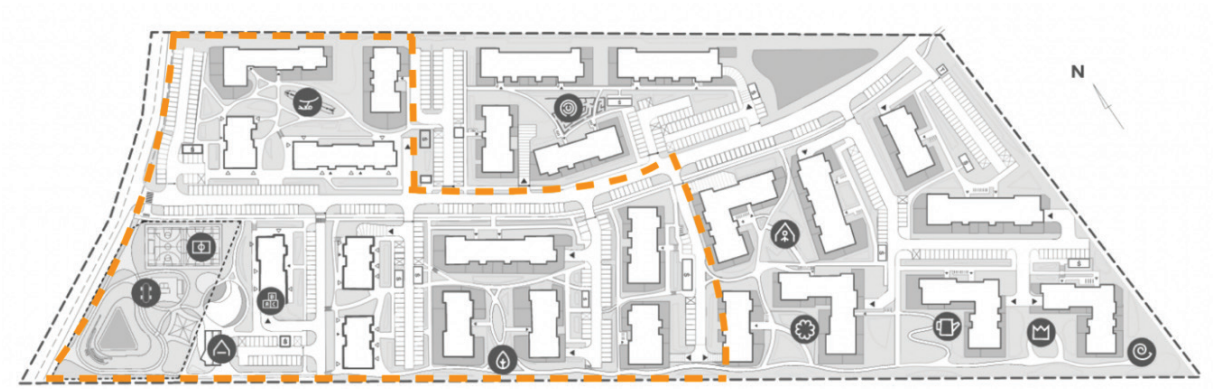


Fig. 6.5. Gdynia, the plan of Beaufort's housing estate, chosen fragment
Rys. 6.5. Gdynia, plan osiedla Beuforta, wybrany fragment
Source: https://boldshift.io/case-study/euro-styl/.

[20] https://korter.com.pl/osiedle-beauforta-pogorze [access: April 2022].

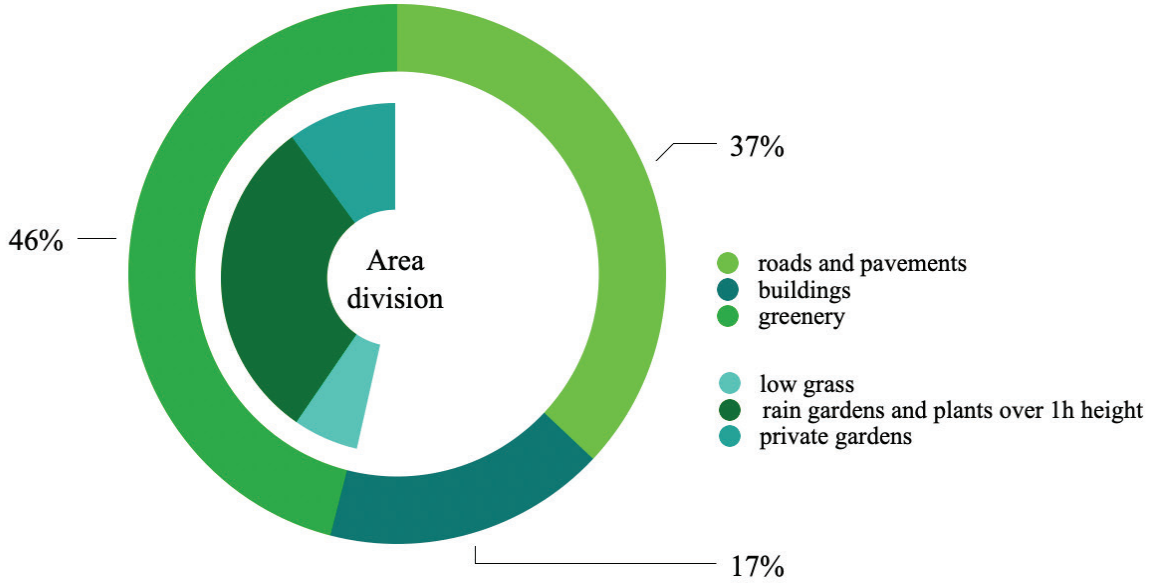


Fig. 6.6. Area division at Beaufort's housing estate
Rys. 6.6. Podział terenu na osiedlu Beuforta

6.4.2. Digital terrain model and terrain profile

The researched area is plane. The digital terrain model (Fig. 6.7A) doesn't show much darker grey colour that could testify about big high differences. Differences approximately 1m in height can be noticed on the terrain profile (Fig. 6.7B). Total length of measured area is 546,13 m. The length of the sections up is 273,1 m and the length of the sections down is 273 m. The highest point is at 69 m, the lowest point at 68 m.

The topography of the area changed due to architectural project and underground parking. The area above parking is lifted about 1.5 m up what causes a slope. In result green courtyards are greenery on the car park slab in fact what is not an issue in this particular case because water is directed through open channels and underground pipes to other parts of the area, where can be easily infiltrated.

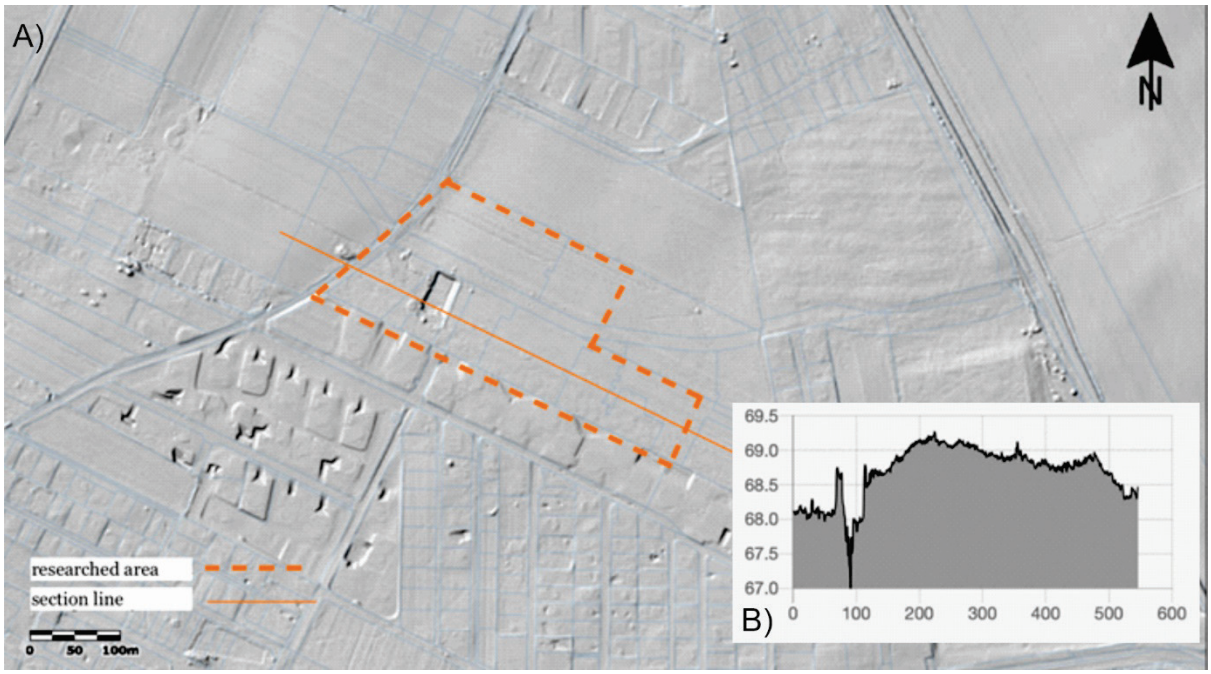


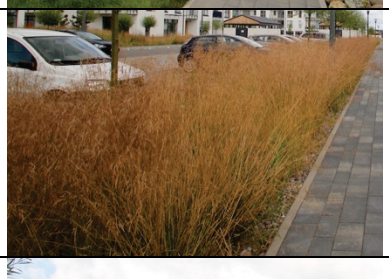
Fig. 6.7. Digital terrain model (A) with terrain profile (B), Beaufort's houisng estate
Rys. 6.7. Numeryczny model terenu (A) z przekrojem profilu (B), osiedle Beauforta
Source: geoportal.com.

6.4.3. Rainwater system

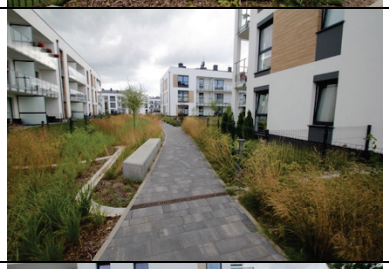
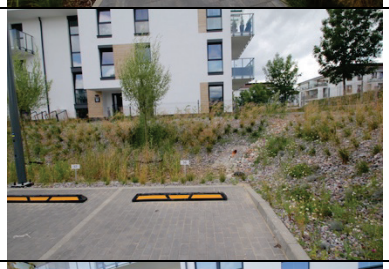
The RMS of the estate is based on rain gardens collecting rainwater from the roofs of residential buildings and water from surface runoff from impermeable surfaces. The direction of water flow is manipulated by a system of open troughs and lowering curbs. Additionally, a retention reservoir has been designed as a flood control reservoir. It was placed on the main access road to the estate together with the recreation and sports area. The slopes of the land were created due to the underground garages. The component elements of this RMS are (Table 6.3): different types of greenery, impermeable, partly permeable, and permeable surfaces, various methods of directing the water (open channels, underground pipes, high differences), and natural irrigation methods.

Table 6.3

Component parts of elements of the rainwater system

Category	Type	Picture, Foto PGM 2021
Greenery	Low greenery	
	Greenery up to 1 m	
	Trees – crown diameter around 1.5 m	
Surfaces	Impermeable: asphalt	
	Impermeable: concrete bricks without the phase	
	Permeable: gravel various sizes	

continue table 6.3

Method of directing the water	Slight drops of hights	
	Open channels, underground pipes	
Irrigation method	Surface runoff from the impermeable surfaces	
	Rainwater from the roofs	

Author's photography, 2021.

The following breakdown shows the typology of elements of RMS (Table 6.4) . This RMS strategy is based on various shapes and form raingardens, troughs and emergency water pound that support the system in case of overflooding.

Table 6.4

Elements of rainwater system

S	A	Picture	Name and main goal	Description
LT	4		Linear trough along communication infrastructure – infiltration with temporary retention	Linear niche accompanying communication infrastructure. Gathering water from the surface runoff and water directed from different areas by underground pipes. Bottom filled with gravel.
SR	6		Small (<2 m^2) raingarden – infiltration	Small basin placed along pedestrian paths. With greenery. With emergency overflow directing access of rainwater to the sewage system or others parts. (Possibly above underground parking)
IR	14		Inner courtyard raingarden – temporary retention	Larger depression in the inner courtyard. Gathering water runoff from pedestrian paths. With emergency overflow directing access of rainwater to the sewage system. (Possibly above underground parking)
IRR	7		Inner courtyard raingarden – temporary retention	Various size basins in the inner courtyard. Gathering water runoff from pedestrian paths, rainwater from the roofs and water directed with open channels from different areas. With emergency overflow directing access of rainwater to the sewage system or other parts. (Possibly above underground parking)
PT	12		Trough along parking – temporary retention	Gathering water runoff from pedestrian paths and parking, rainwater from the roofs and water directed with underground pipes from different areas With emergency overflow directing access of rainwater to the sewage system.

continue table 6.4

MI	8		Micro linear infiltration	Part filled with gravel catching and infiltrating water from roof.
GP	6		Small (<2 m^2) green pocket – short time retention	Green basin along pedestrian path. Catching access water from surface runoff. (Possibly above underground parking)
EP	1		Emergency water pond – retention	Big retention reservoir design as an emergency pound that retain and slowly infiltrate water during extremely heavy rains. Protection against downpours.

Author's fotographies, 2021. S-symbol. A-amount.

According to the designer, the main goal of rain gardens is to water surrounding greenery. Due to that, there is no need to use additional artificial infiltration systems. Greenery of the inner courtyards is, in fact, the green roof that has certain water capacity because of fixed soil thickness. The water is directed by underground pipes into bigger raingardens where can be naturally infiltrated. I n this case green roofs have an impact of the microclimate of the space because of medium high greenery and retained water.

Fig. 6.8. Typical element of rainwater system at the Beaufort's housing estate – raingarden
Rys. 6.8. Typowy element systemu gospodarowania wodą deszczową na osiedlu Beuforta – ogród deszczowy
Source: author's photo, 2021.

6.5. Mickiewicz housing estate (Warsaw)

6.5.1. Description of the researched area

The estate is located in Warsaw, northern part of the city in the district Bielany. About 7 km away from the center. Construction of the estate started in 2018. All of eight buildings are already put in the use. Buildings have six levels. On the area of the estate there are both on the ground parking and underground, two level parking[21]. Estate has BREEM certificate and several architectural awards e.g., *Architectural Award of the Mayor of the Capital City of Warsaw 2020 for the best housing estate, the Green Eagle of the Rzeczpospolita daily for pro-ecological activities, the National Labor Inspectorate Award "Build safely", a distinction in the "Accessibility Leader 2020" competition organized by the Association of Friends of Integration and the Society of Polish Town Planners.*

[21] https://korter.com.pl/osiedle-mickiewicza-warszawa [access: April 2022].

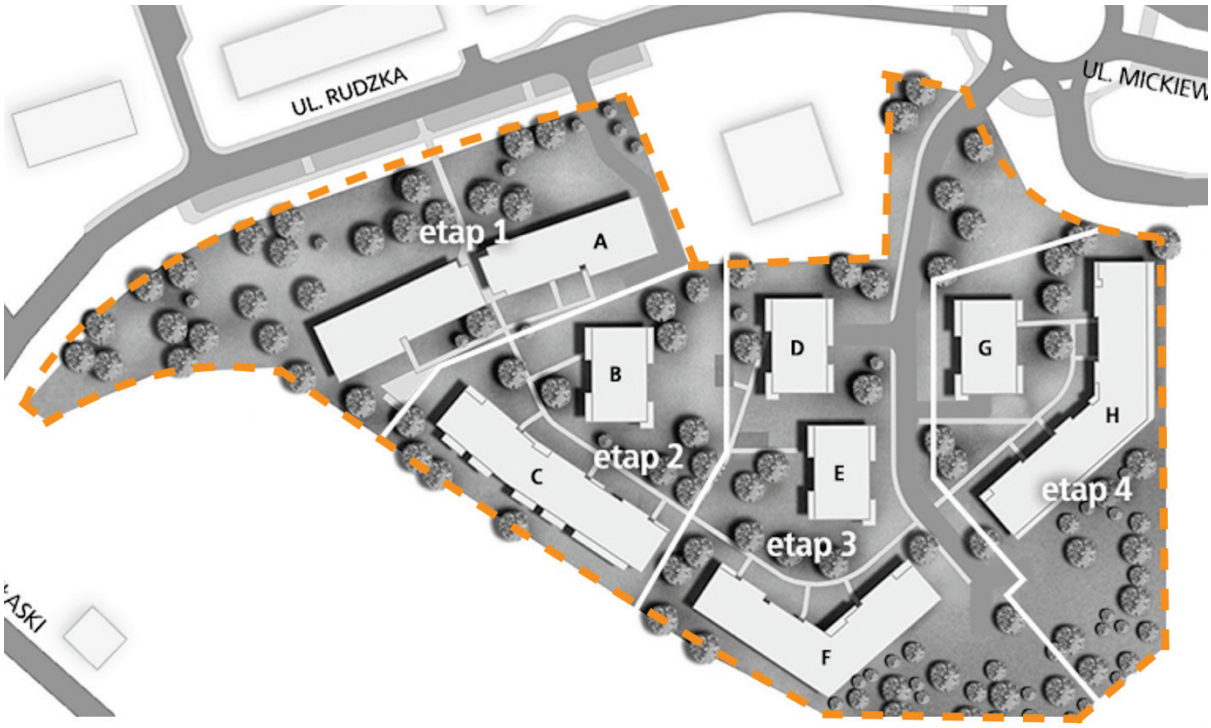


Fig. 6.9. The plan of Mickiewicz housing estate, chosen fragment
Rys. 6.9. Plan osiedla Mickiewicza, wybrany fragment
Source: https://mieszkaj.skanska.pl/nasze-projekty/osiedle-mickiewicza/osiedle-mickiewicza-iii/.

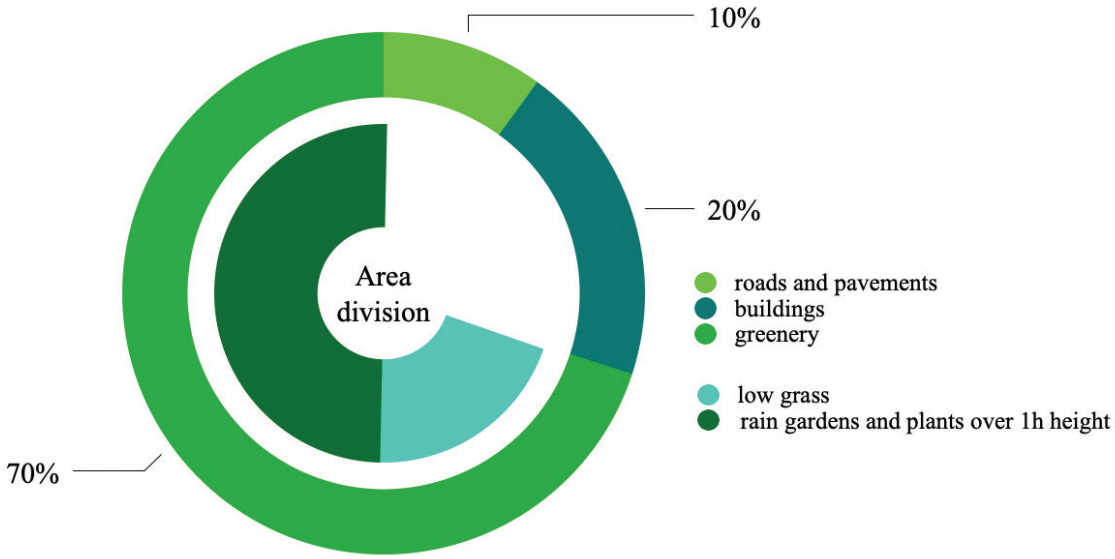


Fig. 6.10. Area division at Mickiewicz housing estate
Rys. 6.10. Podział terenu na osiedlu Mickiewicza

The study covers area of 25 000 m^2. It consists of eight buildings and inner recreational area (Fig. 6.9). Roads and pavements account for 10%, buildings for 20% and permeable surfaces for 70% of the total researched area. Permeable surfaces are divided into low grass (70%) and greenery up to 1m and trees (30%) (Fig. 6.10).

It is worth to notice that high value of permeable surfaces is due to unique design of fire safety infrastructure. The access for emergency vehicles is designed by adding about 3 m of geogrid belt along 2 m pavements made of concrete bricks without a phase. It is the only example on area with existing mature trees preserved during construction.

6.5.2. Digital terrain model and terrain profile

The area of the estate is flat, which can be seen on the numerical terrain model (Fig. 6.11A) generated from the geoportal. The terrain profile (Fig. 6.11B) shows maximum 1.5 m differences in hights. The total length of measured area is 169 m. Total length of sections up is 85 m, total length of sections down is 84 m. The highest point is at 85 m, and the lowest point at 83 m, what gives about 1.7 m difference in height. That difference in height shown on the profile can be observed on the side as slight depression with greenery.

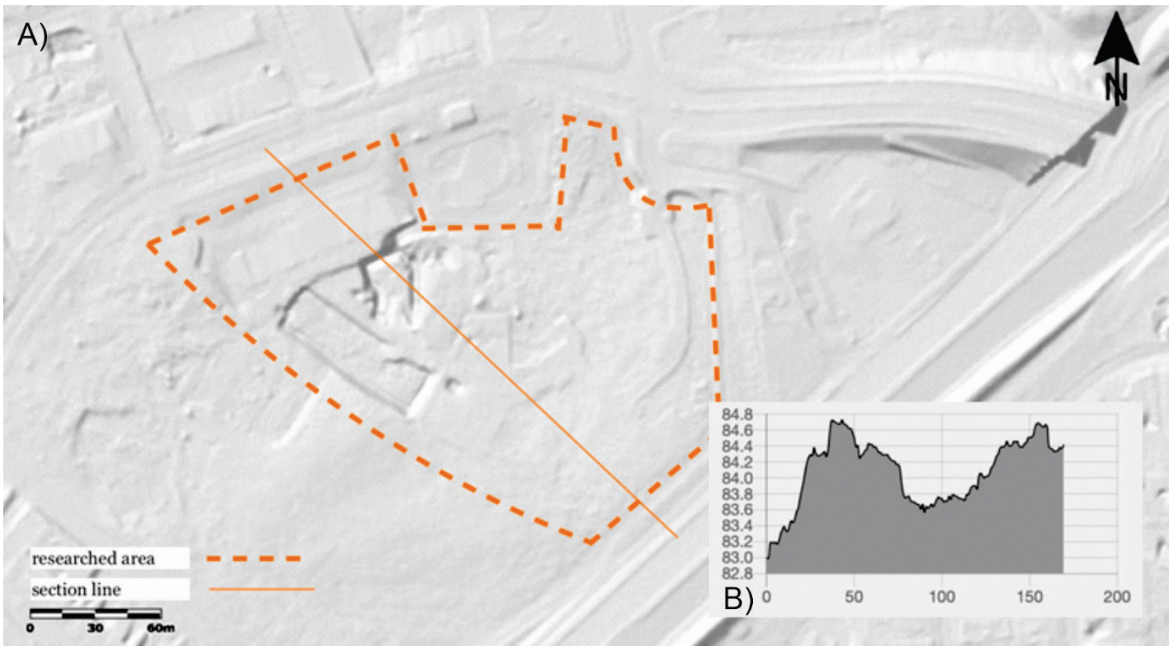


Fig. 6.11. Digital terrain model (A) with terrain profile (B), Mickiewicz housing estate
Rys. 6.11. Numeryczny model terenu (A) z przekrojem profilu (B), osiedle Mickiewicza
Source: geoportal.com.

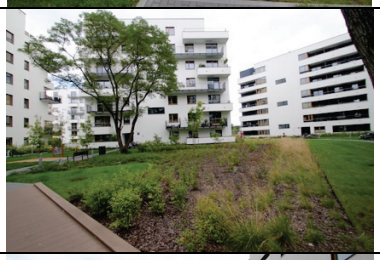
6.5.3. Rainwater system

The estate has a relatively high percentage of biologically active area. This is not only green, but also the use of partly permeable surfaces. The layout of the estate was combined with the existing greenery. Especially, mature trees with wide crowns were left. Nevertheless, some of the greenery is placed above underground parking which has

a negative impact of infiltration area. No rainwater is collected from the roofs and there is no additional artificial irrigation applied. The main element of RMS is partly permeable surfaces that increases the biological active area. Some slight depressions in terrain are observed. Component part of the RMS at this housing estate (Table 6.5) differs from the previous examples because it missing roof runoff catchment, the only source of the rainwater is the rain and some surface runoff. Besides that the housing estates has vrous types of greenery, impermeable and partly permeable surfaces.

Table 6.5

Component parts of elements of the rainwater system

Category	**Type**	**Picture, Foto PGM 2021**
Greenery	Low grass	
	Greenery over 1m hight	
	Trees: wide crawn	
Surfaces	Impermeable: concrete bricks without phase	
	Partly permeable: geo-grid	
Irrigation method	Surface runoff from the impermeable surfaces	

Author's photography's, 2021.

The following breakdown shows the typology of elements of RMS (Table 6.6). The nature based solution that can be recognized at the housing estate are flower beds and depression in the ground, but its highly questionable whether they were designed for retention reasons or purely esthetical.

Table 6.6

Elements of rainwater system

S	A	Picture	Name and main goal	Description
CD	1		Depression with green cascades – temporary retention	Deep depression with cascades of greenery capturing water pouring directly on the ground.
SD	3		Small (<2 m^2) depression – temporary retention	Element collecting water from surface runoff from the pavement. Accompanying greenery.
FB	18		Flower beds – increase in the absorptive capacity of the area	Flower beds captures water from the surface runoff and access of the water during heavy rains.

Author's photography's, 2021. S-symbol. A-amount.

The amount of greenery in the estate is impressive (70% of the total area), but it should be noted that it is mainly grass. Most of the terrain is flat. The lack of depressions in the terrain means that water from surface runoff cannot be temporarily retained and is directed to the sewage system. Moreover, big about of trimmed lawn causes luck of biodiversity. Apparently, the rainwater from the roofs is not collected but wasted in the sewage system. In Warsaw, the average annual rainfall equals 695 mm[22]. The area of roofs is around 5,500 m^2 what gives annually almost 4,000 m^3 of water that fills sewage systems from where is directed to the rives and end up in the sea.

[22] https://pl.climate-data.org/europa/polska/masovian-voivodeship/warszawa-4560/ [access: April 2022].

6.6. Conclusions

One of the strategies of Water Smart City is to restore the natural drainage capacity of cities by introducing nature based solutions. The successful strategy and therefore the system of rainwater management requires a composition of various elements that help to retain, infiltrate, store, treat, adapt to climate changes, and drain the rainwater. The main focus of the research were greenery types, surface types, irrigation method, and NBS that fulfill the aspects of the Water Smart City strategy.

For rainwater to be useful, it should feed the urban ecosystems. Big amount of biologically active area doesn't have an impact on increasing retention capacity if the water from roofs is directed to the sewage system. RMS was identified in first two research residential estates. In case of Green Meridian and Beaufort's housing estates, area of parking, some roads and pavements and greenery excluding private gardens and some main roads is the area of the RMS. Some roads have connection with overflow to the sewage. In both of the estates, there is a great number and variety of elements temporary retaining and infiltrating the water. Gravity is the force moving water between elements. Apart from that, the fact worth mentioning is a proportion between types of greenery. In both of the cases the highest percentage stands for greenery over 1 m height. In Green Meridian low grass and private gardens are around half of greenery itself what is more, comparing to Beaufort's estate, where low grass and private gardens is about 1/3 of the greenery. Apparently, at Mickiewicz housing estate, no water connection between possible RMS elements was found. What is more, no water from the roofs is collected, but directed to the sewage system. Therefore, despite big amount of biologically active area (70%), there is no increasing in retention capacity. Identified elements that could shape the RMS are few and placed in rather coincidental way, lucking plan in whole. Even though greenery is strictly connected to the water, RMS cannot be based just on big amount of trimmed lawn.

Fig. 6.12. Typical element of rainwater system at the Mickiewicz housing estate – flower bed
Rys. 6.12. Typowy element system gospodarowania wodą deszczową na osiedlu Mickiewicza – rabata kwiatowa
Source: author's photo, 2021.

Without planning the water direction and connection to the elements, they are just individual parts catching water falling directly on them. The trend of managing the rainwater is present in two out of three investigated housing estates. Despite that it is really positive that all of presented solutions meet NBS criteria. Those are elements that are cost-effective, imitate natural ecosystem and natural circulation of the water, provide biodiversity benefits and have positive impact on the reception of the space.