GDAŃSK UNIVERSITY OF TECHNOLOGY

FACULTY OF ARCHITECTURE

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MASTER'S THESIS

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DECLARATION regarding the diploma thesis titled:
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ABSTRACT

The thesis is devoted to the problem of minimising negative effects of climate change in cities by green infrastructure. This was used in the case of Mały Kack district in Gdynia.

In the theoretical part there was an overview of the main climate change effects, like urban heat island or urban flooding. There was shown a concept of a resilient city and green and blue infrastructure as its element. It was discussed what is actually the part of green and blue infrastructure and which particular mitigating solutions were used in different cities. There was also presented a division of basic greenery systems.

In the application part, there were analysed aspects important from the greenery point of view. It was made in different scales, starting with the scale of the Metropolitan Area of Tricity, ending in the scale of the district and neighbourhood. There was also made a research of local urban heat island, by temperature measurements, which showed that in relatively small site, the differences in temperature occur. Although the analyses proved that this part of the city is rich in green areas, there could be a lot of improvements done. That is why in the design part there were proposed solutions like green roofs and walls in existing buildings, and also a new net of connections of green areas, gained by tree lanes and elements of green infrastructure.

Key words: green infrastructure, climate change effects, resilient city, greenery systems

Scientific disciplines, according to OECD: social sciences, socio-economic geography, urbanism

STRESZCZENIE

Praca poświęcona jest problemowi minimalizowania negatywnych skutków zmian klimatycznych w miastach za pomocą zielonej infrastruktury, na przykładzie dzielnicy Mały Kack w Gdyni.

W części teoretycznej pracy dokonano przeglądu głównych skutków zmian klimatycznych, takich jak miejska wyspa ciepła czy miejskie powodzie. Przedstawiono koncepcję miasta odpornego i zielono-niebieskiej infrastruktury jako jego elementu. Omówiono, co składa się na zielono-niebieską infrastrukturę i jakie konkretnie rozwiązania o działaniach mitygujących zastosowano w różnych miastach. Wskazano także podział na podstawowe typy systemów zieleni.

W części aplikacyjnej przeanalizowano aspekty ważne z punktu widzenia zieleni. Dokonano tego w różnych skalach, zaczynając od skali obszaru metropolitalnego, kończąc na skali dzielnicy i sąsiedztwa. Przeprowadzono również badanie lokalnego zjawiska miejskiej wyspy ciepła, poprzez pomiary temperatury, które wykazało, że na stosunkowo niewielkim obszarze występują różnice temperatur. Mimo, iż analizy pokazały, że dana część miasta jest bogata w tereny zielone, to można jeszcze dużo w niej pod tym względem ulepszyć. Dlatego w części projektowej zaproponowano rozwiązania między innymi w postaci zielonych dachów i ścian na istniejących budynkach, a także nową sieć połączeń terenów zielonych, uzyskaną dzięki szpalerom drzew i elementom zielonej infrastruktury.

Słowa kluczowe: zielona infrastruktura, skutki zmian klimatycznych, mitygacja, systemy terenów zieleni

Dziedzina nauki i techniki, zgodnie z wymogami OECD: nauki społeczne, geografia społeczna i gospodarcza, urbanistyka

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1. INTRODUCTION AND GOAL OF THE THESIS

1.1. Introduction

One of the greatest challenges nowadays is undoubtedly climate change. The effects of this phenomenon are seen on the whole Earth and have a huge impact on the life of all of us, even if it is not noticed at first glance. These effects have its source in intensified global warming, which is worsened by anthropogenic reasons. As most of the global population lives in cities, they are the place that may exacerbate the situation, but as well, if they are designed in a proper way, they may help to reduce the effects of climate change. One way to increase the abilities of the city to protect from threats may be a concept of a resilient city. Its necessary element is using green infrastructure as a mitigation tool.

1.2. Goal and scope of the thesis

The main goal of the thesis is creating improvements in green infrastructure, which may be used as a solution to the effects of climate change. It is needed to study how these effects influence cities and what kind of problems they cause. The concept of a resilient city is briefly present, as the thesis is focused on green infrastructure, including different forms of greenery and systemic approach. There are also analysed case studies presenting some existing solutions on how green infrastructure helps to reduce the effect of climate change.

In the application part there are carried out analyses of green areas and issues connected with them in different scales: the scale of metropolitan area, the scale of city and scale of district. The subject area is the west part of Mały Kack in Gdynia and its surroundings. The effect of the work will be a system of green infrastructure and new designed solutions, which will help to improve and enhance connections between complexes of greenery in the chosen site.

THEORETICAL PART

2. CLIMATE CHANGE EFFECTS IN CITIES

According to the report of the Intergovernmental Panel of Climate Change from 2021[1], the phenomenon of global warming has been intensified by the activity of humans since 1750, when there was observed the increase of greenhouse gases in the atmosphere. Also, the temperature for the last four decades was higher than in any previous one. Since 1850 the global temperature has risen by about 1°C. Another important information is that since 2007 more people live in cities than in rural areas and nowadays the percentage of them equals about 55%[2]. Although the problem is global, the effects of it, and also activities of mitigation, appear or have to be conducted on a local scale. Below there will be presented some local effects of climate change and their human impact in nowadays cities.

2.1. Urban heat island and its effects on public health

The first phenomenon, that is described deeper in the thesis, is the urban heat island. The more people live in cities, the bigger the area they cover, so the quantity of build-up surface is also rising. In a typical city, the most dense structures are the city centres, but also the suburbs become more built-up. Of course, we cannot stop the development of the cities, but it should take place in a sustainable way - there should be balance between the artificial surface and biologically active surface. Due to its properties, artificial surfaces, like asphalt, concrete or roofs covered with felt, have low albedo and absorb more sunlight than they are capable of reflecting. As a result, when they are gathered together, the temperature of the area rises (fig. 2.1, 2.2).

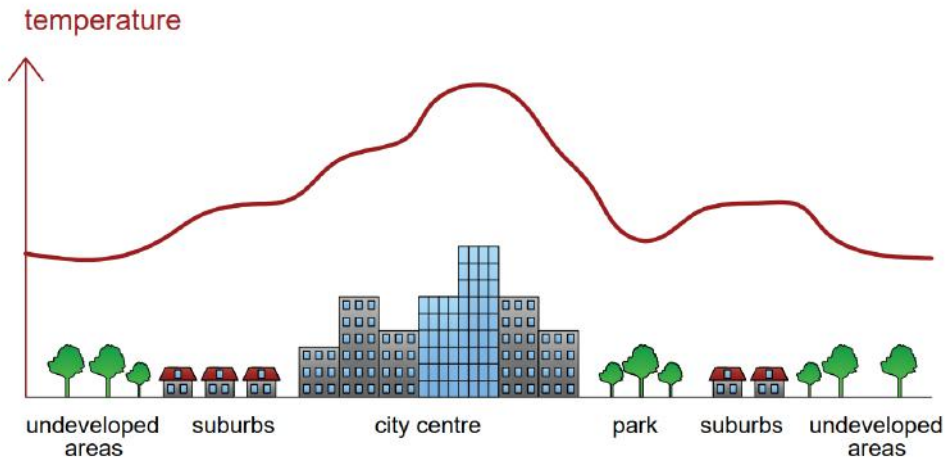

Figure 2.1. Scheme of creating an urban heat island. Own elaboration

[1] *Climate Change 2021: The Physical Science Basis* [online]. Intergovernmental Panel on Climate Change, https://www.ipcc.ch/report/ar6/wg1/ [available: 29.09.2022].
[2] *Urbanization* [online]. Our World in Data. November 2019, https://ourworldindata.org/urbanization [available: 29.09.2022].

Moreover, there are some additional factors that have an impact on the occurrence of this effect. If there is a lack of natural areas covered with plants, there is less transpiration. It results in more energy gathered in the atmosphere and buildings. Also, the significant influence has the density and height of buildings, because between them there may appear a street canyon effect, which affects air circulation. Tall, vertical and artificial walls reduce the speed of wind and absorb a lot of sunlight. That is why the orientation of buildings must be designed in compliance with main wind directions to provide a proper circulation in the city. Another factor is connected with intensified human activities in urban areas. Heat for example from traffic movement, industry and air conditioners deepen the effect of urban heat island.

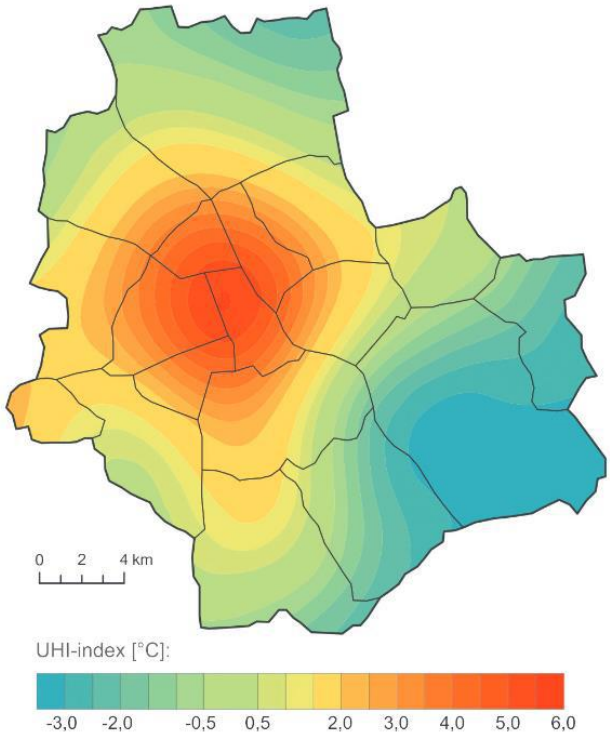

Figure 2.2. Map of the temperature intensity in Warsaw, May 2011. Source: http://rcin.org.pl/Content/56055/WA51_74963_r2014_Miejska-wyspa-ciepla.pdf

The rise in the temperature, together with heat waves in summers, which are the effect of global warming, may have a crucial impact on human health (fig. 2.3), explained by Błażejczyk[3]. The nights in the cities can be warmer than in the countryside even for several degrees. That is why organisms are not able to regenerate properly from the high temperature and thermal pressure is imposed for every day of heat. What is important, there takes place a harvesting effect - the health consequences are seen after several days, so there is a significant dependency on the length of the phenomenon.

[3] *Miejska wyspa ciepła w Warszawie* [online]. Warszawa: Wydawnictwo Akademickie SEDNO, 2014, http://rcin.org.pl/Content/56055/WA51_74963_r2014_Miejska-wyspa-ciepla.pdf [available: 29.09.2022]

There are also groups of people that are especially versatile to the long-term high temperatures. Among them there are elderly people, disabled people, people with mental, vascular cardiac and respiratory diseases, pregnant women and little children. Another factor is social isolation, connected with living alone and staying at home. Crucial meaning also has social status, depending on economic factors. People with low-socioeconomic status are more liable to heats, because they have worse living conditions, accessibility to air conditioning and health care.

Urban heat island has a negative influence on the quality of sleep, as the wake phase is getting longer and the phases NREM and Rem are getting shorter. It results in, for example, the body temperature, heart action and usage of oxygen, which may result in hypertension, diabetes or sclerosis and then in higher risk of brain and cardiovascular complications. It was examined that high temperature increases the number of people with heart attacks, cardiac failures and cerebral vascular accidents.

Not only do heats have an impact on the cardiovascular system, but also on the respiratory system. However, the diseases connected with this system might also be a result of pollution in cities. But the examination also shows that the growth in temperature contributes to more cases of pneumonia and more people in hospitals with chronic diseases like asthma.

The visible effect of heat on human skin is sweat, as an effect of thermoregulation. When the temperature of skin, which in thermal comfort equals 28 to 32 degrees, is getting higher than the temperature of the surroundings, the excess of heat is removed from the organism with the sweat. But collaterally there are also removed valuable liquids and soils.

There are different symptoms connected with overheating of organisms, but the most dangerous of them is called heatstroke. It appears when the internal temperature of the human body is higher than 40 degrees and it is dangerous to life. As a result, there may appear not only some less harmful symptoms, like suffocation, weakness or vomit, but also some more serious, like renal failure.

Figure 2.3. Some of the health problems that could be a result of urban heat island. Own elaboration

Another important factor that should be taken into account is allergenicity. It was examined that the effect of urban heat island influenced the increase of allergenicity of plants.

When the temperature is higher, plants produce more pollen, and this pollen also contain more protein, which draws symptoms of allergy. Moreover, the vegetation period becomes longer, and plants pollinate earlier. This all may cause asthma attacks, conjunctivitis or skin changes. That is why the species of plants should be chosen properly.

Figure 2.4. Dry lawn as an effect of a drought. Source: Łukasz Cynalewski / Agencja Wyborcza.pl, https://www.tokfm.pl/Tokfm/7,103085,27370744,przez-zaniedbania-systemowo-pozbywamy-sie-wody-ekspert-o.html

Figure 2.5. Drying up the Vistula River. Source: Kuba Atys / Agencja Gazeta,, https://www.polityka.pl/tygodnikpolityka/nauka/1629907,1,zabojcza-susza-jakie-moga-byc-jej-konsekwencje.read

Results of heat waves in summer are easily seen in the landscape of cities. The lawns, especially the mowed ones, are drying up and getting yellow (fig. 2.4.). Also, the level of water in rivers decreases and the bottom of the watercourses is seen (fig. 2.5.).

2.2. Urban flooding

Effects of climate change could be seen on a local scale as more and more often occurring extreme weather conditions. For example, the amount of rain during the year is almost the same as in the previous years, but there are longer periods of droughts and stronger rainfalls. It has a crucial impact on cities, which have to adjust their infrastructure to very dynamic occurrences. Taking into account below-mentioned rainfalls can change apparently calm streams into disruptive watercourses. The reason why the water is accumulating is the fact that there is not enough biologically active surface, so the runoff must be transported to the storm water or sewage system and could not infiltrate directly to the ground where it fell.

Among the floods, the most dangerous ones are the flash floods. They appear and disappear suddenly on the local scale, and often last less than six hours. When there appears to be an overflow of water, because the storm water systems are not efficient, the phenomenon is called an urban flood.

In Tricity one of the biggest floods took place after the rainfall at night between 14th and 15th of July 2016[4]. In Gdańsk, Wrzeszcz suffered a lot, according to the overflow of

[4] Hukało P.: *Wielka ulewa w Gdańsku w 2016 r. Trzy lata temu deszcz zatopił wiele ulic miasta* [online]. Dziennik Bałtycki. 14.07.2019, https://dziennikbaltycki.pl/wielka-ulewa-w-gdansku-w-2016-r-trzy-lata-temu-deszcz-zatopil-wiele-ulic-miasta-zdjecia-wideo/ar/c1-12255725 [available: 29.09.2022]

Strzyża Stream. The underground floor of a mall was flooded and many trams were damaged. As a result of this accident, two people died. If not for the infrastructure that was built after the previous such a big flood in 2001, the effects could be even bigger and more dangerous. However, this case shows that more should be done, as the storage reservoirs might be not effective enough. Building infrastructure to keep the overflow of water is not the only solution. The reason why so much water flows in one place, is that it could not soak into another. It is the result of developing new settlements without enough biologically active surface. In the case of Gdańsk, these are the south located districts, like Jasień, Ujeścisko, Łostowice.

In the same night, in Gdynia, many damages were caused by the Kacza River, a 14 kilometres long watercourse flowing through the south districts of the town. Several bridges for pedestrians and one bridge for vehicles were destroyed and the areas of allotment gardens located by the river were flooded (fig. 2.6.). In addition, a part of a small square with an old willow located next to the estuary was undercut and taken to the sea (fig. 2.7.).

Figure 2.6. Destroyed entrance to the bridge on Kacza. Own photo

Figure 2.7. The estuary of Kacza after the rainfall.. Own photo

2.3. Strong winds

Not only are the rainfalls getting stronger, but also the winds. As the differences between pressure in different areas could change more dynamically, the possibility of occurring extreme weather conditions gets higher. As an example, one of the biggest thunderstorms that appeared in the Pomeranian region in August 2017 could be used (fig. 2.8.). The wind was so strong that it demolished 42 hectares of forests in the voivodeship. As a result of this extreme phenomenon 6 people died. During this thunderstorm, mostly the woody and rural areas suffered, however, that night in the whole country almost 5000 buildings were destroyed.

The wind plays a significant role in the city. It is responsible for venting, cooling down and removing pollutants. However, the strength of the wind may be escalated by the form and the arrangement of buildings. It is called the canyon effect[5]. When longitudinal buildings are located collaterally to the dominating wind directions, the strength becomes higher and pollution

[5] Zielonko-Jung K.: *Miasto i wiatr* [online]. Architektura&Biznes, 9.05.2019, https://www.architekturaibiznes.pl/miasto-i-wiatr,1738.html [available: 28.11.2022]

moved by wind gathers at the end of the canyon. When wind blows perpendicularly to the buildings, pollution accumulates on the windward side. The air circulates and moves to the opposite site in the bottom part of the structure. Also, in the most dense structures, like complexes of urban blocks, air stasis may appear. That is why it is important to leave in the cities some open spaces to enable venting.

Figure 2.8. Forest after a thunderstorm in August 2017, Bory Tucholskie, Poland. Source: Marek Matecki/ Lasy Państwowe, https://bydgoszcz.tvp.pl/55314908/cztery-lata-po-nawalnicy-w-borach-tucholskich

2.4. Lack of biodiversity

Urbanisation is listed as one of the main reasons for decreasing biodiversity, next to deforestation and developing agriculture. Biodiversity could be defined as the variety of forms of life on Earth. It can be defined by the variety in genetics, species and ecosystems. Unfortunately, human activities in the last decades contributed to a decrease in biodiversity. The environment is getting more and more polluted, many habitats are being destroyed and many species have worse conditions and less places to live.

Living Planet Report from 2018 shows, among others, that between 1970 and 2014 a decline in the population of vertebrates equals 60%. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services report from 2019 states that humans changed 75% of the land environment and 67% of the water environment. Crucially, the number of wetlands is decreasing, which makes many species of amphibians endangered. This all testifies that something should be done to stop or at least cramp these processes.

3. RESILIENT CITY

An answer to the problems, the concept of resilient city was proposed in the 70s by Holling in the ecological aspect. In his opinion, resilience means the capability of the ecosystem to keep the original state after natural disasters. Later, the term resilience was extended to economic, epidemiologic and psychological aspects. So a resilient city is resilient not only to hurricanes or floods, but also to social segregation, pandemics or economic failures - generally to all negative changes. This city quickly adapts to new conditions. Building a strategy for a city must have an answer for the question, what it should be resilient to. The problems that a city has to be resilient to, can be grouped into four main categories, presented in table 3.1.

Table 3.1. Threats to a city. Own elaboration based on: Bilska A.: Proces budowy miasta odpornego na przykładzie Rotterdamu, 2016.

Category of factors	**Examples**
Environmental	Floods, droughts, earthquakes, hurricanes, tsunami
Economic	Unemployment, inefficient sectors of economy
Social	Terrorism, social exclusion, criminality
Infrastructural	Bad quality of roads, no sewage system, poor street lighting

There should be explained how the resilient city can be built and there are several stages of it[6]. The first one is identifying the risks, how sensitive for them the city is and how these risks are predictable. The interactions between different elements of the city should be examined to see how the threats are spreading. As the systems of cities are quite complicated, the next step is creating cooperation between different stakeholders: local communities, public administration, entrepreneurs, society, institutions and organisations. As a result of this cooperation, there should be possible effective strategic planning. Finally, the plans should be realised and the city can differently react to threats - mitigate their results, resist them or adapt to them.

The thesis is focused on mitigating the climate change effects by green infrastructure, so it is related to the original meaning of the resilient city. The next chapter would explain more about this tool.

[6] Bilska A.: *Proces budowy miasta odpornego na przykładzie Rotterdamu* [online]. In: Rozwój Regionalny i Polityka Regionalna 34, 2016, s. 59-78. Instytut Geografii Społeczno-Ekonomicznej i Gospodarki Przestrzennej UAM, https://core.ac.uk/download /pdf/144757.pdf544 [available: 29.09.2022]

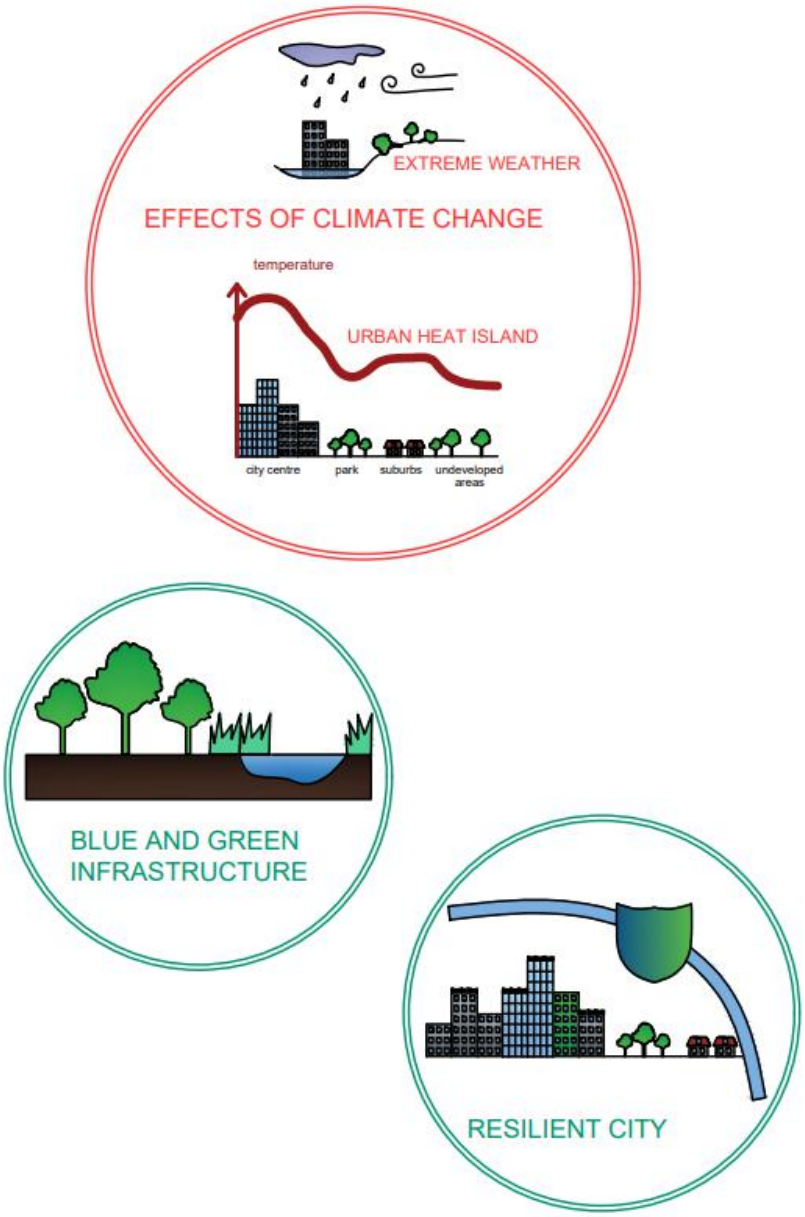

Fig. 3.1. A scheme presenting that adding blue and green to the city makes it more resilient to the effects of climate change. Own elaboration

4. GREEN AND BLUE INFRASTRUCTURE AS AN ELEMENT OF RESILIENT CITY CONCEPT

4.1. Elements of green and blue infrastructure

Firstly, it should be explained what green and blue infrastructure actually means. The European Union defines it as a planned net of natural and semi-natural areas, which are designed and managed to provide ecosystem services, like cleaning water, air quality or climate change adaptation.

The elements of the infrastructure could be determined in different ways. The first one is based on the scale[7]. In this division, there are six elements featured (tab. 4.1.), starting with the core areas, often protected and with a good level of biodiversity. Then there are the restoration zones - new areas for particular species and sustainable usage areas, like multifunctional forestry or agricultural lands with high natural value. The next one are green urban and peri-urban green functions: here are parks, gardens, green walls and roofs, allotment gardens, ponds etc. Two last types of elements are relevant to connectedness. The ones that provide natural connections are for example hedges, rivers or green belts, and the artificial ones - animal pathways, like bridges and tunnels.

Table 4.1. Elements of green infrastructure. Own elaboration based on John, H., Marrs, C., Neubert, M. Podręcznik zielonej infrastruktury – Tło koncepcyjne i teoretyczne, terminy i definicje, wersja skrócona w języku polskim, 2019

Element of green infrastructure	**Examples**
Core areas	Natura 2000 protected areas, forests, water
Restoration zones	Reforestation zones
Sustainable use	Multi-use forests, High Nature Value farming systems
Green urban and peri-urban areas	Parks, gardens, ponds, allotment gardens, green walls and roofs
Natural connectivity features	Hedges, wildlife stripes, riverbanks
Artificial connectivity features	Green bridges, tunnels, fish passes

Another division is based more on technical features. The index made by the Ecological Institute and Sendzimira Foundation listed ten elements of green and blue infrastructure[8]. The first five ones are related to water, and there belong: water retention ponds,

[7] John H., Marrs C., Neubert M. [red. 2019]. *Podręcznik zielonej infrastruktury – Tło koncepcyjne i teoretyczne, terminy i definicje, wersja skrócona w języku polskim* [online]. Project Interreg Central Europe MaGIC Landscapes. Produkt O.T1.1, Drezno.Z udziałem: Z. Jała, D. Wojnarowicz, https://www.interreg-central.eu/Content.Node/MaGICLandscapes-Podrecznik-Zieloney-Infrastruktury.pdf [available: 29.09.2022

[8] *Błękitno-zielona infrastruktura dla łagodzenia zmian klimatu w miastach. Katalog techniczny* [online]. Berlin - Kraków: Ecologic Institute & Fundacja Sendzimira, 2019,

bioretention basins, bioswales, infiltration trenches and bioretention planters. Their role is to accumulate and infiltrate the overflow of water. The next three ones are the solutions in buildings - there are green bus stops, green roofs and green walls or facades. Finally, the last two ones are connected with the surface - to make them permeable or use the structural surface.

Starting with the water-related ones, water retention ponds are permanently filled with water and have additional retention capacity. The main reservoir bowl should gather at least double of the average yearly amount of rainfall. They also should have a sedimentary basins, which would purify water before it gets to the main basin, and a storm water runoff. Their banks should be densely planted with domestic species of emergent, floating and submerged plants - in Middle Europe these are rushes, orrises or sedges. The ponds are dedicated to dewatering mainly the areas between 3 to 10 hectares.

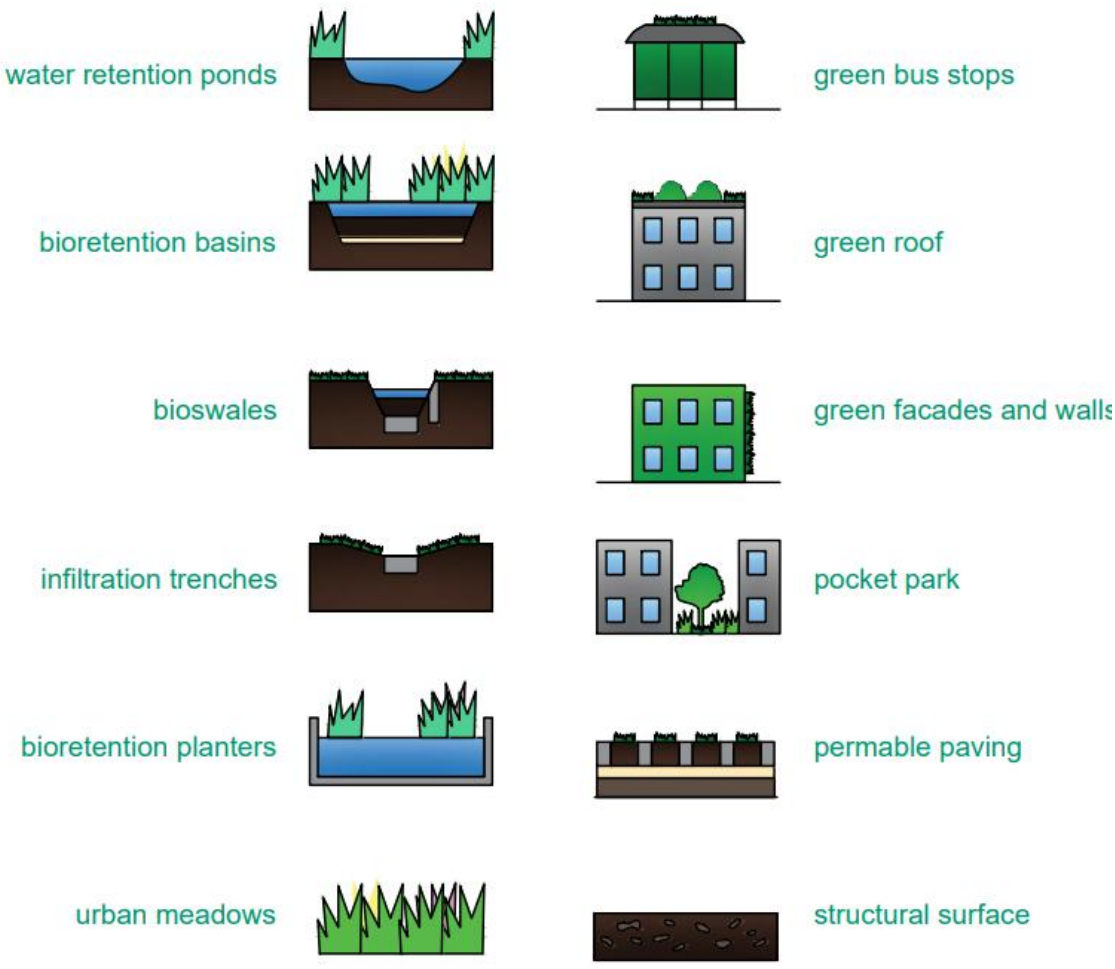

Fig. 4.1. Symbolising the elements of blue and green infrastructure. Own elaboration based on: Błękitno-zielona infrastruktura dla łagodzenia zmian klimatu w miastach. Katalog techniczny, 2019

https://www.ecologic.eu/sites/default/files/publication/2020/3205-blekitno-zielona-infrastruktura-dla-lagodzenia-zmian-klimatu-w-miastach-katalog-techniczny.pdf [available: 29.09.2022]

Bioretention basins are used in the most urbanised areas, with a lot of artificial surfaces. They form densely planted areas, only periodically wet. They consist of several layers, beginning with a grass buffer zone, which slows down the runoff, and detention zone, where the overflow of water gathers. Then there is an optional layer of organic matter, which helps to remove pollution. The main zone is a retention-filtration layer, made mainly from sand-clayish bed. At the bottom of the basin there is a permeable layer and drainage layer with a pipe. There should also be taken into account the storm water runoff and ensuring proper watering plants in dry periods. They are a good solution on a smaller scale, the most optimal for 1 hectare.

Bioswales are ditches located mainly along roads, parkings and paths. They are linear forms with the intersection of parabola, trapezium or letter 'V' and they are 1,5 to 5 metres wide. They consist of two main layers, whose role is to filter and infiltrate rainfall: sand-compost layer and coarse-grained gravel layer. It also must have a join to storm water runoff. In case of preventing erosion, the slopes around the bioswales should not have more than 5% in order to work most effectively.

Infiltration trenches are flat ditches filled with stones or crushed stones. They help to reduce surface runoff and flood risk. A trench consists of a surface layer from gravel and a drainage layer from thick aggregate protected with geotextile. It should have a pipe under the aggregate layer, put in a slope with maximum 2% and the bottom of the trench should be located at least one metre above the groundwater level. This solution is useful for a maximum 5 hectares of catchment area.

The last element connected with water are bioretention planters, which might be also called rain gardens in containers. There are two types of them - the first one has an impermeable bottom with drainage pipes and the second one has an open bottom, by which water infiltrates easily to the ground. Both types have concrete walls, a layer with vegetation, retention-filtration layer and drainage layer. Bioretention planters can be implemented in a very flexible way in many locations and are very attractive in public spaces.

The next group of elements are relevant to architecture solutions. Take green bus stops at first (fig. 4.4.). The most effective ones not only have greenery on a roof, which gather rainfall, later transported by a pipe, but also green walls, covered with climbing plants. Behind the shelter there should be situated a retention bin, where the water and runoff is gathered and the plants are growing. If it is necessary, the overflow of water could be moved to the green areas nearby.

Another effective and complex solution are green roofs. There are two main types of them, extensive and intensive. On extensive green roofs (fig. 4.3.) there grow low-demanding vegetation, like moss, grass or stonecrops, which need little maintenance and thin layer of soil. Intensive green roofs (fig. 4.2.) are more comprehensive. More diverse plants can grow on them, but they need more effort in creating and preserving. They also have functions of open public gardens or spaces for residents. In extensive roofs, under the vegetation, there is a

substrate layer, then a drainage layer and in the bottom a protective layer. Intensive roofs require a more complicated system of layers. The substrate layer should be thicker than in extensive roofs, then there is a filtration layer, drainage layer, anti-root mat and an insulating layer. What should be also noted, the construction of the building has to be resilient enough to carry all the layers and vegetation. But green roofs not only increase the amount of green areas in cities, but also have a positive impact on efficient energy use of buildings and can reduce the surface runoff up to 90%.

Figure 4.2. Intensive green roof in Warsaw. Source: Maciej Fijak, https://smoglab.pl/ogrody-buw-20-lat/

Figure 4.3. Extensive green roof in Staffordshire, the UK. Source: https://specifierreview.com/2018/07/24/sedum-roof/

Figure 4.4. Intensive green roof in Warsaw. Source: FPP Eviro, Białystok City Office, https://www.lifetreecheck.eu/en/Databaze/2019/Green-Bus-Stops

Figure 4.5. Green wall in Kreuzberg, Berlin . Source: Sergej Glanze / FUNKE, https://www.morgenpost.de/nachhaltigkeit/article233689249/Gruene-Fassaden-fuer-ein-besseres-Stadtklima.html

Improvement in thermal insulation of buildings is possible also by green facades and walls (fig. 4.5.). As they do not need a huge cover of ground, they could be implemented even in the most dense structures of city centres. The walls absorb carbon dioxide and pollutants, so they have a positive influence on air quality. There are some types of green walls, depending on what kind of plants are creating them and how they are planted. When climbing plants have adventitious roots, which enable directly sticking to the wall, like for example ivy, they need no additional construction. However, there should be no cracks or slits in the wall. The supporting

construction is necessary when there grow plants with pulvillus or springs to twist around the balks, like vine or clematis. Plants can be put directly in the ground, in a planter at the bottom of the wall or in a serie of pocket pots attached to the facade. In the last case, there is usually a watering and fertilising system implemented.

Applying permeable paving is one of the easiest ways to increase the water infiltration. It is possible by using sponge materials, like porous concrete or gravel, or by leaving some gaps for vegetation between the elements of the material, for example between concrete paving blocks. Permeable paving should replace hermetic artificial surfaces wherever it is possible. However, they should not be used in the closest vicinity of possible pollution sources.

The idea of using structural surfaces means adding to soil more organic matter, peat or biochar in designated and needed proportions. Biochar increases the ability of retention, absorbs heavy metals and other pollutants and supports gathering carbon dioxide in soil.

Last two solutions, that will be described below, were not mentioned in the index, but are important from the urban point of view and could be also listed as the elements of green infrastructure. Urban meadows are plant communities with flowering and melliferous domestic species. They can be designed and grow from a prepared mix of seeds, or appear naturally in the places where lawns are rarely mowed. Although the second type could be less colourful than the first one, not only grass appears there. This kind of area decisively increases the level of biodiversity in cities.

Figure 4.6. Paley Park in Manhattan, New York - an example of a pocket park. Source: Sampo Siklo, https://www.pps.org/places/paley-park

Finally, the idea of a pocket park should be presented (fig. 4.6.). A pocket park is an enclave of greenery that could be implemented on a relatively small area, an empty lot or few, or even smaller. In city centres, where every square metre is valuable, they constitute a

possibility to increase greenery and permeable surfaces. However, a pocket park also has functions dedicated to human use - they should create a place where people can integrate. That is why they have to take into account the needs of different users.

One important thing about green and blue infrastructure is the word infrastructure used in this term. It indicates the importance that green areas, watercourses and water reservoirs should create a coherent net and not be fragmented. Their continuity significantly increases their effectiveness. For example, it makes it much easier for animals to migrate, and it could be compared in this aspect to ecological corridors. They work on a regional scale and green infrastructure work on smaller scales. So the greenery should create a system in cities and there are several basic types of them.

4.2. Typology of greenery systems in cities

There are many factors that determine the specific shape of the system, which is strictly related to the urban composition of each city. Among these factors, many are connected with areas that are inhospitable for development, so where it is very difficult to situate buildings and these areas are kept green. Including these environmental issues, there could be listed wetlands, flooding areas and areas with high denivelation with some declivities or landslides. Linear forms of greenery are often determined by the location of watercourses. From an anthropogenic point of view, very significant is the system of arteries: roads, rails and pedestrian paths.

Generally, in literature there are four basic types of greenery systems in cities: a spotted system, a ring system, a radial/cuneiform system and a striped system. However, they are often mixed and in plans of cities there can be seen some combinations of these systems. Also, some of the authors add and describe in detail some of the combinations, which can be easily identified for its characteristic features, as another type of system. For example, Czarnecki [1968] mentions a ring-radial system and Orzeszek-Gajewska [1982] adds a spotted-cuneiform system and a ring-cuneiform system, which actually have some differences comparing to ring-radial system, which will be explained later.

The first type is a spotted system. It may be in fact a problem with calling it a system, because it is formed, accidentally, by scattered spots of greenery in the city. Their location is mainly based on the historical gardens, old palace parks, graveyards, monastic gardens etc., but also some solutions that appeared later, like sports grounds and parks from the turn of the 19th and 20th century [Ptaszycka, 1949]. The idea of using this system in planning was promoted by Eugene Henard at the beginning of 20th century [Czarnecki, 1968]. He focused on the recreational needs of people and prepared a plan of Paris with steadily located green areas, however this solution might not be good for microclimatic, aesthetic and compositional conditions.

Another type is a ring system, whose origin is usually connected with the defensive function of cities. In the 19th century, in many European towns, the fortifications, including defensive walls, lines of circumvallation and fosses, were not necessary and they were

inhibiting the development of cities, so it was started to remove them. The places after these objects were levelised and transformed into ring-shaped green areas, called in Poland plant parks. Their name actually comes from the word ‘plantowanie’, which means levelling the surface of the ground. This idea of a ring system was approved by urbanists and they suggested creating other rings of greenery with intervals of 1 to 1,2 kilometres. For example, there was thought to make a large ring of forests and meadows around Wien in the end of 19th century. The ring system is also seen in the famous concept of Garden Cities created by Howard. Nowadays, the plant parks could be easily seen in the plans of many cities as a ring around the Old Towns. The most famous example from Poland is Krakow, but there are also some smaller towns, like Chełmno, Rawicz or Paczków (fig. 4.7. and 4.8.).

Figure 4.7. and 4.8. Green systems in the structure of central parts of Krakow and Rawicz. Own elaboration.

The next type, which is a radial system (fig. 4.9.), penetrates the structure of the city and joins the green areas in the centre with the peripheral sphere covered with forests, meadows and fields around the city. Its shape is based mainly on the main radial-composed roads. Areas along these roads were developed, in contrast with the areas located between them, which were worse communicated, had less value and often had unfavourable conditions, because of the presence of rivers, wetlands or high denivelations. That is why they were transformed into cuneiforms of greenery and for this reason this type is also called a cuneiform system. However, the cuneiforms could not be necessarily situated in a radial form, because

this type may be more dependent on the environmental conditions than the shape of the roads. For example, it could look more organic, when through the city there flows a river with some tributaries and main green areas are located along the watercourses. That actually means that a cuneiform system is a wider term than a radial system.

The last of the main types is a striped system (fig. 4.10.). It may be seen in the cities with geometric, hippodamian plans. The stripes of greenery can have different widths and cross irregularly. These green areas may form boulevards and comfortable routes for pedestrians. This system can be represented by many cities in Russia and the United States of America.

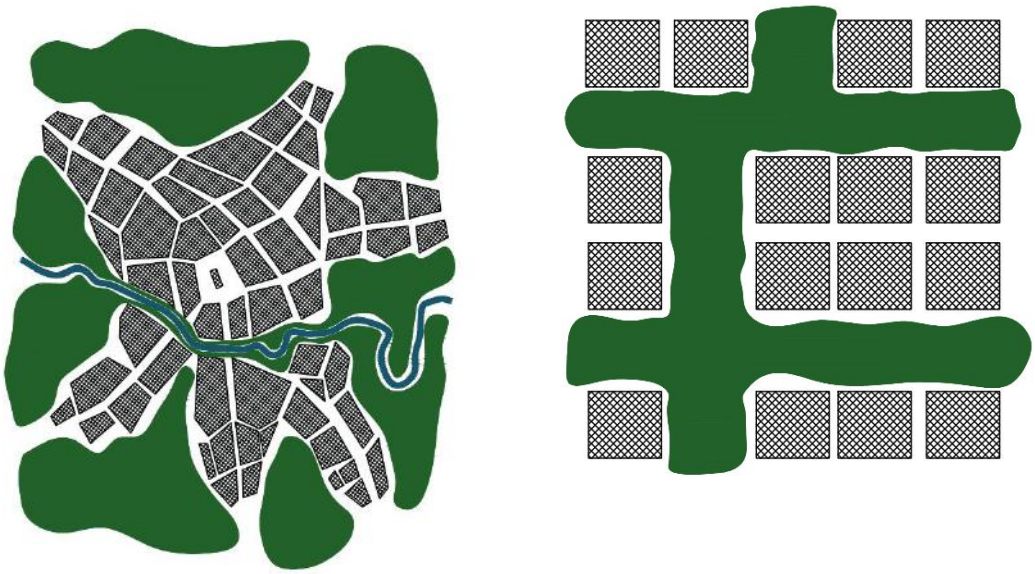

Figure 4.9. and 4.10. Theoretical schemes of radial system and striped system. Own elaboration

First example of a mixed type is a ring-radial system, whose model was presented by Pepler [Czarnecki, 1968]. It has the advantages of both systems, but the best feature of it is the continuity of the system. The cuneiforms divide the city, but the rings join it again. In this model there should be at least one ring inside and one outside, nevertheless they do not have to be regular and form an actual ring, but adapted to local conditions. When the cuneiforms are not situated in a radial form, there can be identified a ring-cuneiform system. A spotted-cuneiform system appears when the cuneiforms located along the rivers merge with the spots of greenery of housing settlements.

Very interesting study was made by Orzeszek-Gajewska [1982], who focused on microclimate and analysed the behaviour of wind in different types of green systems. There was an examination of the situation in Poland, where winds dominate from the west. Take account of a ring system at first. When the trees are planted along the shape of the ring, the power of the ring is decreasing in the east and west part of the ring, and increasing in the north

and south parts. Another situation occurs when the trees are planted across the ring, and then the power of the ring is dependent on the width of the green belt.

4.3. Classification of green areas in cities

The most basic division of greenery is made on how people transform it, so it is more wild or more cultivated, and if it is low greenery with domination of herbaceous plants and bushes or tall greenery with mostly trees. There should be more expanded classification made.

Green areas in cities could be divided into five main categories [Czarnecki, 1982]. The first one is the available greenery, which is dedicated to the common usage for all the people. It may be represented by parks, squares, boulevards and promenades. The second category is the greenery with a special destiny, which can be for example insulating and communicational greenery, as well as graveyards, allotment gardens and educational gardens: botanical, zoological or ethnographic. The next one is greenery that accompanies areas with different functions. There are also areas dedicated to agriculture and forestry, like garden farms, seedbeds or orchards. The last type are areas for trips and recreation, among which there can be distinguished forests, historical parks and national parks.

So, actually the division made by Czarnecki takes into account different functions that green areas can have in cities. Although, it should be noted that green areas may appear in different forms. In the size factor, it can be diversified park and square, and even if the border between these two terms may be blurred, especially when the term pocket park came into life, there is no doubt that park is a larger form than a square. Also, groups of trees could create different forms, based on how they were planted in parks or along streets. If trees grow only on one side of the street or path, they form a lane, and if on two sides - alley. Trees can also constitute a clump, and a single tree, which is especially exposed in the area, is called a tapeworm or a solitaire. Bushes could be planted in hedges and flowers may form a wild meadow, rounded or striped flowerbed or be put into pots.

5. IMPLEMENTATION OF GREEN INFRASTRUCTURE IN CITIES - CASE STUDIES

Many cities have already realised the problems that are effects of climate change and implemented a lot of green solutions in their structure. Here will be make an overview of these solutions in different scales.

Starting with the scale of the city, the first idea is a net of green venting corridors in Stuttgart, Germany[9]. The reason for creating such a net was minimising the effects of urban heat island and pollution in the city. There was done a complex analysis of local climate factors and environmental issues gathered in a climate atlas for the region. Stuttgart is located in a valley and the speed of winds there is low. The temperature in the city is much higher than in its surroundings because venting is ineffective and too weak. For the same reason, the air is polluted from traffic and the motor industry. So, there were analysed, among others, the most frequent wind directions and temperature distribution. In the climate atlas there were also designated areas where development should be limited in order to prevent from gathering cold air.

Figure 5.1. Green corridors in Stuttgart. Source: LHS Stuttgart (Amt 61), M. Storck. https://sendzimir.org.pl/wp-content/uploads/2021/07/NBS1_2_8_Siec-zielonych-korytarzy-przewietrzajacych-w-Stuttgarcie.pdf

Based on the analysis, there were four green venting corridors planned in the structure of the city (fig. 5.1.). They were delimited along the main valleys which join forested hills outside

[9] *Błękitno-zielona infrastruktura dla łagodzenia zmian klimatu w miastach. Katalog techniczny* [online]. Berlin - Kraków: Ecologic Institute & Fundacja Sendzimira, 2019, https://www.ecologic.eu/sites/default/files/publication/2020/3205-blekitno-zielona-infrastruktura-dla-lagodzenia-zmian-klimatu-w-miastach-katalog-techniczny.pdf [available: 29.09.2022]

the city with its centre. The corridors were connected with the existing parks in the city. Each corridor should be at least 100 metres wide. The obstacle of creating such corridors is the high value of properties, so there could be a temptation to build on the green areas. That is why, how every individual investment would impact on air circulation is analysed.

Although the centre of Stuttgart is very densely built-up, the next case described is even more dense and implementing there green corridors is more complicated. Barcelona in Spain is known for its regular structure consisting of dozens of quadrangular urban blocks (fig. 5.2.). For making the city more sustainable, there was implemented the idea of superblocks.

A superblock is a form bigger than one urban block, but smaller than a neighbourhood. It actually consists of nine regular urban blocks, forming a huge quadrangle. Inside it, the traffic is limited and streets are dedicated for pedestrians. Cars are able to move around the block, crossing it is possible only for residents and services, and with limited speed. The streets changed into recreational public spaces with greenery. As there is no need for roadways, there is much more place to plant trees and introduce permeable surfaces. New green areas appear mainly at the intersections of roads.

Figure 5.2. Implementing greenery in Barcelona. Las Ramblas avenue. Source: https://www.spain.info/gcc/en/images/dont-miss-barcelona/

First superblocks in Barcelona were created in 2016, but it is still planned to expand the idea. In Eixample, centrally located district, where Sagrada Familia is situated, there is a plan to extend it to 21 streets[10]. Some of the effects of more greenery are seen now - nitrogen dioxide

[10] *Superblocks. A sustainable strategy for regenerating the city* [online]. Architecture walks and tours in Barcelona, 24.05.2016, https://barcelonarchitecturewalks.com/superblocks/ [available: 28.11.2022]

content in the air decreases, and some are long-term - when the trees grow, there will be more shadow and the effect of urban heat island will be reduced.

Take an example from the other side of the Atlantic Ocean. In Chicago, the United States, in 2001 there began a project called ‘Green Alley’. It was the solution proposed by the Chicago Department of Transportation, which helped to realise the goals from Chicago’s Climate Action Plan, mainly mitigating and adapting to floods and urban heat island.

One of the ways to realise this idea was to replace impervious surfaces, which covered more than 3500 acres of public alleys in the city, to the permeable ones (fig. 5.3.). Instead of being transported to not everywhere accessible storm sewage system, the water can easily infiltrate to the ground. It would be more sustainable than installing new connections to the sewer system. The overflow of water can be gathered in catch basins. Another solution was using recycled materials and implementing light colours to increase albedo, so more radiation can be reflected, and urban heat island can be reduced.

For 16 years, there have been over 300 green alleys realised. There was also made a handbook for citizens with the proposals to be implemented on their own plots to create a greener city. Easy to understand sketches familiarise residents with the ideas of composting, native landscaping, rain gardens, green roofs and others.

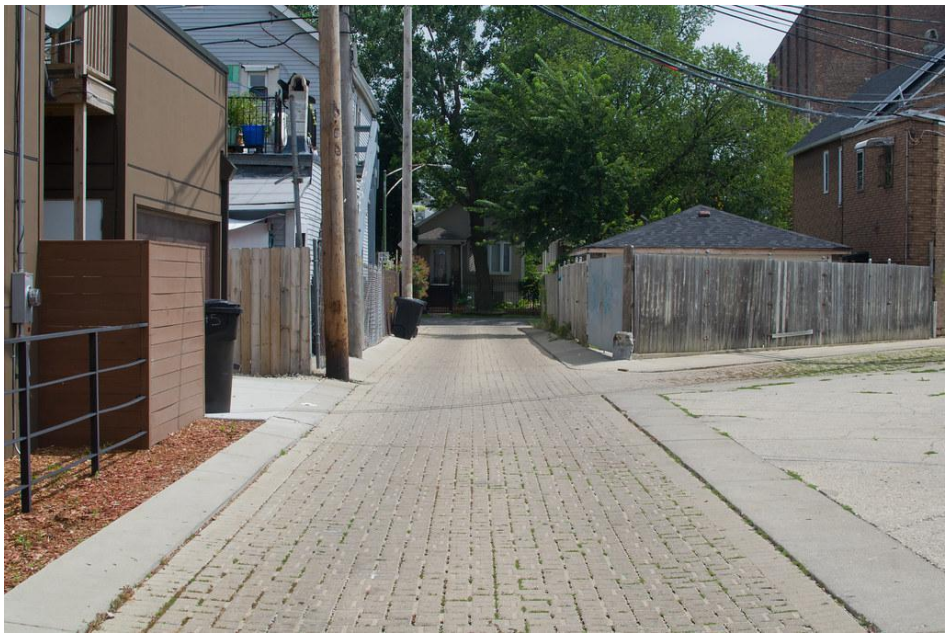

Figure 5.3. Permeable surfaces as the main idea of Green Alley Project in Chicago. Source: https://www.flickr.com/photos/centerforneighborhoodtechnology/14702865060

Moving to some smaller scale solutions and to Poland, take the rain gardens in Gdynia first. The earliest one was released in a city centre, next to the Infobox building located on Świętojańska Street (fig. 5.4.). Water from its roof is guided by blue chutes to a container with moisture- loving plants. This architecturally attractive object was made mainly to inspire people to create more gardens like this.

The next rain garden in Gdynia looks much different. It was built in Meksyk settlement, on Śliwkowa Street and its role is to prevent surrounding buildings from flooding. There is a n underground infiltration system, because there is no sewage nearby. The garden covers an area of 300 square metres and is an attractive public place with planted willows, birches and roses.

Another rain garden in the city is located in Orłowo, along Zwycięstwa Avenue, which reduces the occurrence of water after rainfalls. It has longitudinal shape and is planted with orrises, smartweed and matteuccia (fig. 5.5.).

Figure 5.4. Rain garden in the centre of Gdynia. Own photo

Figure 5.5. Rain garden in Orłowo. Own photo

Each of the gardens looks a bit different, and although they are all called rain gardens in Poland, they probably should be classified as different solutions. However, they play similar roles and are runoff-based ideas.

Take a look at another element of green infrastructure. In Warsaw there is located one of the biggest and most beautiful green roofs in Europe[11]. The garden, because it can be named so, is situated on the roof of the Library of the Warsaw University. It covers an area of over one hectare and it is publicly available. Its designer said that it has two functions: ecological and economic. So, it does not only increase the area of biologically active surface, but also is the reason for lower costs of air conditioning and heating the building.

The case studies overview was started with the largest scale solutions, so it would end in the smallest interventions, because even them are crucial for the local conditions. For example, in Mały Kack district in Gdynia, in the 2020 and 2021 editions of participatory budget, there won a small project. As a result, there were new plantings of groundcover roses and ornamental grasses implemented on a small square next to one of the main crossings in the whole district. Making this improvement in one of the most representative places which until recently has been an empty lawn, helped to increase the aesthetic value of the space and equalled in an increase of biodiversity (fig. 5.6. and 5.7.).

[11] Fijak M.: *Najsłynniejszy polski ogród na dachu kończy 20 lat. Wyprzedził modę o dekady* [online]. SmogLab, 14.05.2022, https://smoglab.pl/ogrody-buw-20-lat/ [available: 28.11.2022]

Figure 5.6. The square in February 2020. Own photo

Figure 5.7. The square in June 2022. Own photo

Last example is one of the latest projects in the campus of Gdańsk University of Technology. Between the Main Building and the Building of Hydromechanics there was designed a new public space. At first it was fully impervious, fortunately, when it was finished, it was realised that there was no point for doing so, and parts of the pavement were removed (fig. 5.8. and 5.9.). These new spaces were scattered with bark and there were planted boxwoods in hedges, columnar yews, white hydrangeas and some other species, that makes this place much more attractive and water absorbing.

Figure 5.8. The public space in September 2022. Own photo

Figure 5.9. The public space in October 2022. Own photo

APPLICATION PART

6. ANALYSIS IN THE SCALE OF THE METROPOLITAN AREA

6.1. General information

Firstly, the widest scale was analysed. It is called in this thesis a Metropolitan scale, however it is not the whole Metropolitan Area of Tricity. The boundaries of the assumed area are rather blurred. As the central subject is the city of Gdynia, the analysis was made in a site about 5 to 10 kilometres from the borders of the city. In the north it is designated by the Reda River and its estuary. In the west it is a line made by some east lakes of Kashubian Lakeland: Marchowo Lakes, Tuchomskie Lake and Otomińskie Lake. The south boundary comes across the south districts of Gdańsk and the eastern next to one of the estuaries of Vistula River - Śmiała Wisła and then through the Gulf of Gdańsk.

Before the analysis of the Metropolitan area is conducted, some general information connected with greenery about the whole voivodeship should be presented. The data from 2020 come from the Polish Central Statistical Office. Pomeranian Voivodeship is one of the most forested regions in Poland, having the third position with the percentage of 36,42 forest cover. When it comes to arable farming, it has the eleventh position - this type of land use covers 42,20 percent of voivodeship. It is in the middle of ranking of the areas covered by parks, street greenery and communal woods. It is the fourth voivodeship, ex aequo with Kuyavian-Pomeranian, Lubusz and West Pomeranian voivodeships, with the biggest cover of gardens. Finally, when it comes to allotment gardens, it has also one of the highest percentage of them.

6.2. Landform

The satellite map was used to check how fragmented the complexes are. Looking at the scale of the Metropolitan Area, there are dominating two large forest complexes with some enclaves. The area of these two complexes is protected by Tricity Landscape Park, that is why the boundaries of them are so visible. However, not all forested areas are within the borders of the park, as well as the park is protecting not only the forested areas, but looking at the wide scale and generalising, they nearly overlap.

Comparing the satellite map with the landform map, it is possible to see the reason why the borders go in that way. Tricity is located on the ground of several mesoregions, which belong to two different stripes of landscapes in Poland: stripe of coasts and stripe of lakelands. The genesis of the whole area is strictly connected with the glacial activity and the effects of it are seen in the landform and differences between regions and mesoregions (fig. 6.1.).

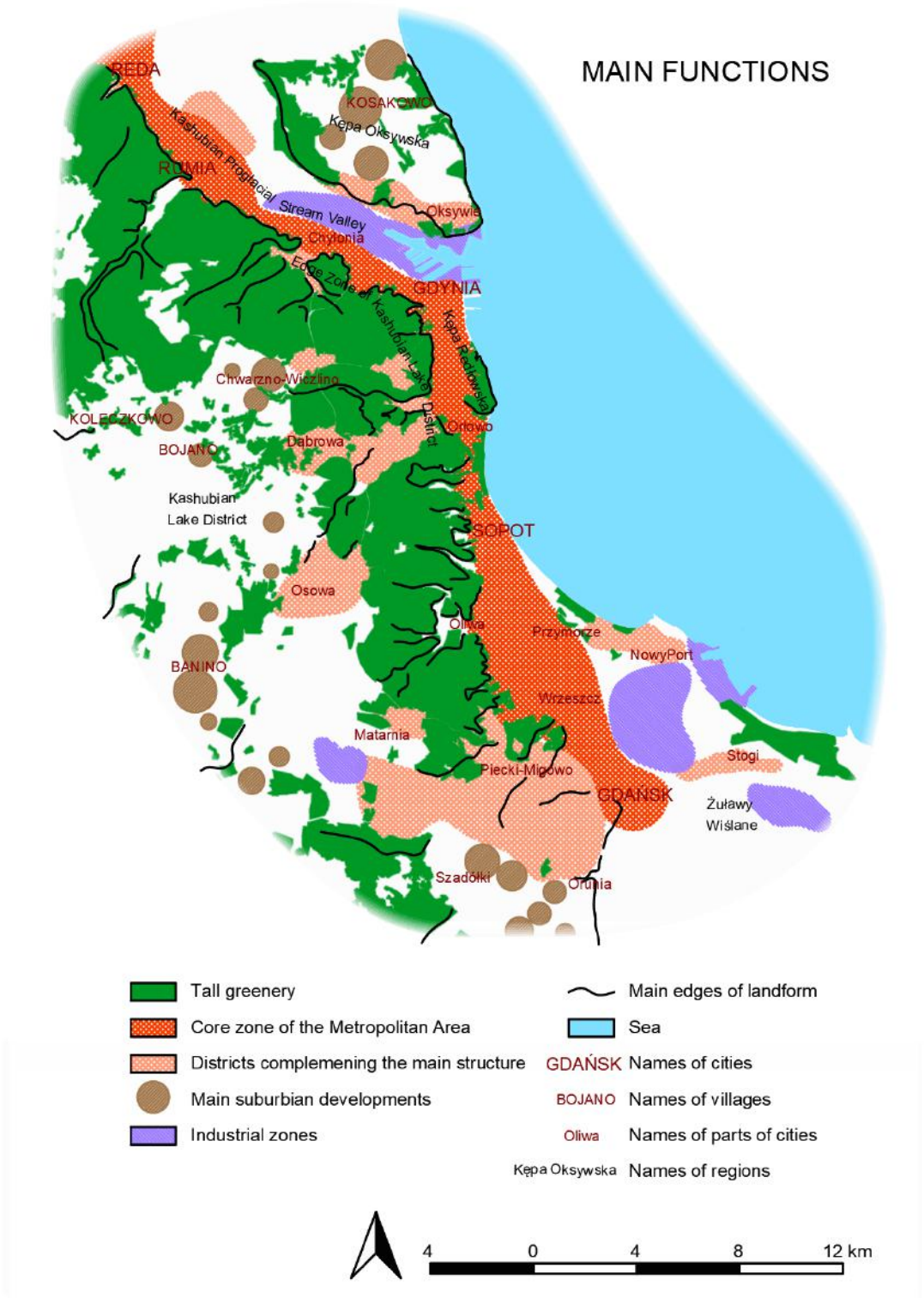

Figure 6.1. Map of the Metropolitan Area of Tricity with the main functions, including tall greenery. Own elaboration

The Metropolitan Area of Tricity is situated on four mesoregions that belong to the stripe of coasts and one mesoregion that belongs to the stripe of lakelands. When it comes to the coasts sphere, the most important ones are Kashubian Coast in the north and Żuławy

Wiślane in the south. The other ones are Proglacial Stream Valley of Reda-Łeba in the north-west and Vistula Spit in the east. However, a huge part of the Metropolitan Area is located on Kashubian Lake District. To see the characteristic of mesoregions, each of them will be briefly described.

The mesoregions of stripe of coasts are not as flat as they seem to be. Take the Kashubian Coast first. It is the area of ground moraine, raised during one of the last stadial of north-polish glaciation and the activity of post-glacial waters. As a result, a rolling area was created, consisting of dips, like Obniżenie Redłowskie, and moraine plateaus, like Kępa Oksywska or Kępa Redłowska, with the heights reaching 90 metres above the sea level.

The origin of the Proglacial Stream Valley of Reda-Łeba is also glacial. Rivers, arised from melting glacier, were joining rivers flowing from the other side, and together streaming collaterally to the front of the glacier. It changes smoothly into the Kashubian Proglacial Stream Valley in the east, where the valley is divided into two arms with Kępa Oksywska in the middle.

Area of Żuławy Wiślane is the most flat one among the others. This land is located in the delta of the Vistula River and is strongly related to the activity of the river. What is characteristic of this land, that there appear some depressions.

The mesoregion of Vistula Spit is associated with the activity of the sea and wind. It is created from forested dunes, of which the highest is 56 metres high above the sea level.

The last mesoregion taken into consideration is Kashubian Lake District. It is distinguished by enriched landforms. Glacier left here outwash plains, moraine hills, groups of erratic rocks and of course many lakes, mainly ribbon lakes and moraine lakes. The heights of this mesoregion reach over 300 metres above sea level, with the Wieżyca Peak - 329 metres above sea level, however, these hills are located quite far away from the Metropolitan Area. Hills that actually should be noted, because are situated in the examined area, are Donas Peak - the highest peak of Gdynia with nearly 206 metres height above sea level, and Student Peak, which is the highest in Gdańsk and has a little above 180 metres.

What should be also observed, between the Kashubian Lake District and Kashubian Coast there is present a zone called the Edge Zone of Kashubian Lake District. It is a terminal moraine, seen clearly in the landscape of Gdynia and cities located to the north-east.

Not only glaciers or sea had an influence on the landform of the area, but also the activity of rivers. The biggest river in the site is the Vistula River and its lower reach has a significant impact on creating the landform, but also the smaller watercourses should not be forgotten. Apart from mentioned above Proglacial Stream Valley of Reda-Łeba with Reda River, they are present several streams and watercourses, like Zagórska Struga, Kacza River or Oliwski Stream, that split the hills of Kashubian Lake District and its Edge Zone, and create valleys.

Having this general overview, now is the time to explain why this all is so important, when the study is about greenery. The landform is a strong determination for human activity. That is why the areas with steep slopes, like particularly the Edge Zone of Kashubian Lake District, are free from development, because it would be very difficult and expensive to locate

there buildings, roads and whole infrastructure. Moreover, adding the factor of the quality of the soil, different areas are at different levels useful for agriculture. That is the reason why the area of Żuławy Wiślane is almost non forested - it is flat and the ground consists of very fertile fen soils.

6.3. Areas covered with greenery

Getting back to the two big forest complexes, it is now becoming understable why their shape looks like that. The valleys of the streams are seen as indents into the Edge Zone. In Rumia it is the development of Szmelta in Zagórska Struga Valley, In Gdynia there are 3 valleys in the north: Demptowo in Gdynia in Demptowski Stream Valley and Pustki Cisowskie in Cisowski Stream Valley with urban development and Marszewo in Marszewski Stream Valley with almost no development. In the south of the city there is the valley of Kacza River with the buildings of Mały Kack. In the case of Gdańsk, there is Oliwa in Oliwski Stream Valley and Niedźwiednik and Matemblewo in Strzyża Valley.

The enclaves, that are visible in the structure of two complexes, are formed mostly by the villages, like Gniewino or Łęczyce, or complexes of villages, like complex of Bieszkowice, Nowy Dwór Wejherowski and Zbychowo and the agricultural lands located around them. The exception is Witomino, an urban district of Gdynia.

Of course, the complexes are sectioned by many roads and paths, but in the scale of the Metropolitan Area they form a coherent entirety. However, they are separated from each other by the development of the southern districts of Gdynia. It arises along current-day Wielkopolska and Chwarznieńska Avenues, which join the central part of the city with the outside. The connections between these two complexes will be searched for in the more detailed analysis in the later chapter.

There are also other important complexes in the surroundings, as the forests protected by Tricity Landscape Park are continued both in the north and in the south. Above the separation made by the development of Wejherowo and Reda, there is located the Darżlubska Wilderness - Puszcza Darżlubska. On the other side there are woods around Otomin, which extend far into the Kashubia.

Other important systems of complexes are created by the forests and parks located along the coast. The first one is quite narrow and stretches for nearly 7 kilometres from Mechelinki to Oksywie. The next is the forest located on Kępa Redłowska, between Wzgórze św. Maksymiliana and Orłowo. It is only about 2,5 kilometres long, but very valuable, as it protects a very unique coast with active cliffs. Moving to the south, there is a complex of greenery formed by the park in Kolibki and North Park in Sopot, which has more wild features in Gdynia, and changes into more organised in Sopot. It stretches for about 3 kilometres. Another quite big system is located in Gdańsk, and it is created by 3 parks: the Jelitkowski Park, the Przymorze Park and the largest one, the Ronald Reagan Park. It also has a length of about 3 kilometres. Then there is the Brzenieński Park and on the other side of the Martwa Wisła the greenery of Westerplatte. Finally, there are two quite big complexes located on islands: the first

one with the length of about 4 kilometres on Stogi Island and the second one, 10 kilometres long, on the Sobieszewska Island.

Finishing the review of most important complexes of greenery, several more should be added. In the north there are some forests between Rumia, Mosty and Suchy Dwór. Then, to the east from Dąbrowa and Osowa districts, there is a mosaic system of small forest complexes. The last greenery area that should be taken into consideration are the green complexes in Gdańsk, located between Wrzeszcz and Piecki-Migowo, being old or current graveyards.

6.4. Existing ecological corridors

According to the information of Polish General Management of Protecting the Environment, there are no existing or planned ecological corridors in the Metropolitan Area of Tricity. The nearest ones are located about 30 kilometres from the central parts of Tricity. These are 3 corridors: the Słowińskie Coast Corridor, the North Kashubian Corridor and the North Bory Tucholskie Corridor.

Of course, the green areas within the borders of Tricity and its surrounding are the habitats for animals as well as the ones that are officially the ecological corridors, so there is also the need for migration between them. This is actually the idea of green infrastructure in the urban areas, as the ecological corridors play an important role in the national and regional scale, the green infrastructure could be implemented as migration routes and habitats in the scale of cities and districts.

6.5. Protected areas

Information about protected areas was based on Tricity Landscape Park website and websites of cities of Gdynia and Gdańsk.

Although there is not any National Park located nearby, a huge part of the site is under protection. The biggest and centrally located form of protection is Tricity Landscape Park. It covers an area of nearly 200 km2 and plays a significant role in the structure of Ticity. There is also another landscape park located nearby, Coastal Landscape Park, situated in the north.

The Tricity Landscape Park was established in 1979 to protect the valuable young-glacial landform. Among the elements of this landform there could be mentioned hills of ground moraine, over a dozen glacial lakes and numerous erratic blocks. Forests cover over 90% of the area of the park, with the domination of pine, beech, oak, birch, alder, poplar, goat willow, rowan, hornbeam and ash. The most common plant communities are beechwood forests and oak-beech forests. Very valuable are lobelian lakes, bog springs, semi-natural meadows and submontane reed beds of manna grass. Among many endangered and rare species of plants there can be mentioned lake quillwort, water lobelia, swedish sorbus, sundew, salvinia, wetland orchid and a group of submontane species, like alpine speedwell, creeping jenny and northern firmoss. On the other side, the most interesting species of animals that live in the park are sea eagles, red kited, black-headed gulls, cranes and kingfishers among birds, boars, deers,

badgers, european water shrews and bats among mammals, crested newts among amphibians, grass snakes and common adders among reptiles and finally brown trouts and lamprey among fishes.

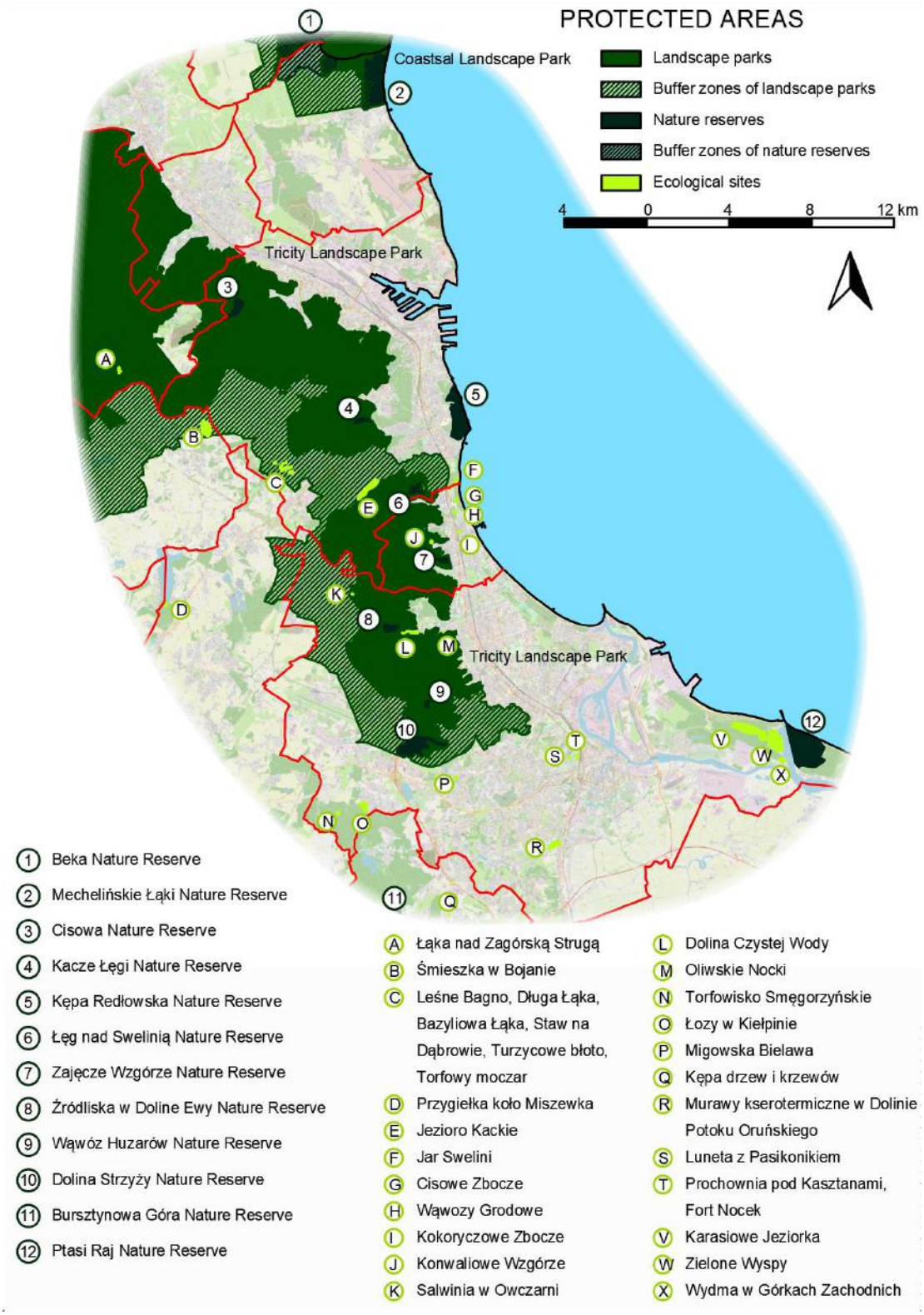

Figure 6.2. Map of protected areas in the Metropolitan Area of Tricity. Own elaboration

On the whole area there are scattered several nature reserves. In the closest vicinity of Coastal Landscape Park there are two nature reserves that protect seaside meadows: Beka Nature Reserve and Mechelińskie Łąki Nature Reserve. However, they are quite separated from the rest of protected areas and they create an individual system, divided by a wide belt of suburban areas of north Gdynia and Kosakowo Community from the system of Tricity Landscape Park.

There are ten nature reserves located inside the Tricity Landscape Park, but three of them are situated in Wejherowo Community and are not seen on the map. The rest of them are within the borders of Gdynia, Sopot and Gdańsk. Three of them are located in Gdynia, also three in Gdańsk and one in Sopot.

The first one in Gdynia is Cisowa Nature Reserve, which is a forest reserve and protects a valley of Cisówka Stream and part of the Edge Zone of Kashubian Lakeland. It was created in 1983 and covers the area of 24,76 hectares. The second is Kacze Łęgi Nature Reserve, which also came into existence in 1983, but is three times smaller - covers the area of 8,97 hectares. The role of this reserve is to protect the part of a riparian forest located in the Kacza River valley, where its tributary, the Źródło Marii Stream, flows into the main river. The next reserve is Łęg nad Sweliną Nature Reserve, which is the youngest Nature Reserve in Gdyna, as it was established in 2005. This area of 13,4 hectares protects riparian and oak-hornbeam forests. What should be noted, the stream is the habitat of a rare platyhelminth, crenobia alpina, which lives only in very clean water.

The only nature reserve in Sopot is Zajęcze Wzgórze Nature Reserve. It also was created in 1983 and covers the area of 11,74 hectares. In the reserve there is located an old-growth forest with beeches with an age more than 200 years. The forest is in the phase of dying back and a new generation of trees appears.

Moving to Gdańsk, the first reserve is Źródliska w Dolinie Ewy Nature Reserve, established in 1983. It has 12,04 hectares and its role is to preserve a valley with riparian woods and rushes. In the south part of Tricity Landscape Park in 2005 there arose Wąwóz Huzarów Nature Reserve. Its area is only 2,8 hectares and it is a floristic reserve. Finally, the southernmost verge of the landscape park is covered with the area of Dolina Strzyży Nature Reserve. It was established in 2007, so it is the youngest of all described reserves and covers an area of 38,52 hectares of environs of the valley of Strzyża Stream.

There are also other important nature reserves that are not located within the boundaries of Tricity Landscape Park. In Gdynia there is Kępa Redłowska Nature Reserve, which is the oldest and biggest in the city - it came into being in 1938 and has 120,08 hectares. It is located by the sea and it is known for protecting the active cliff, where it is possible to observe the abrasion processes. Also, the woods situated on the hills of Kępa Redłowska are very valuable, in them there could be found swedish whitebeam. In Gdańsk, there should be mentioned Ptasi Raj Nature Reserve, located on Sobieszewska Island. It was established in 1959 and covers a huge area of 188 hectares of seaside meadows, rushes and forested dunes.

Within its boundaries belongs two seaside lakes. The reserve is a breeding place for 45 species of birds.

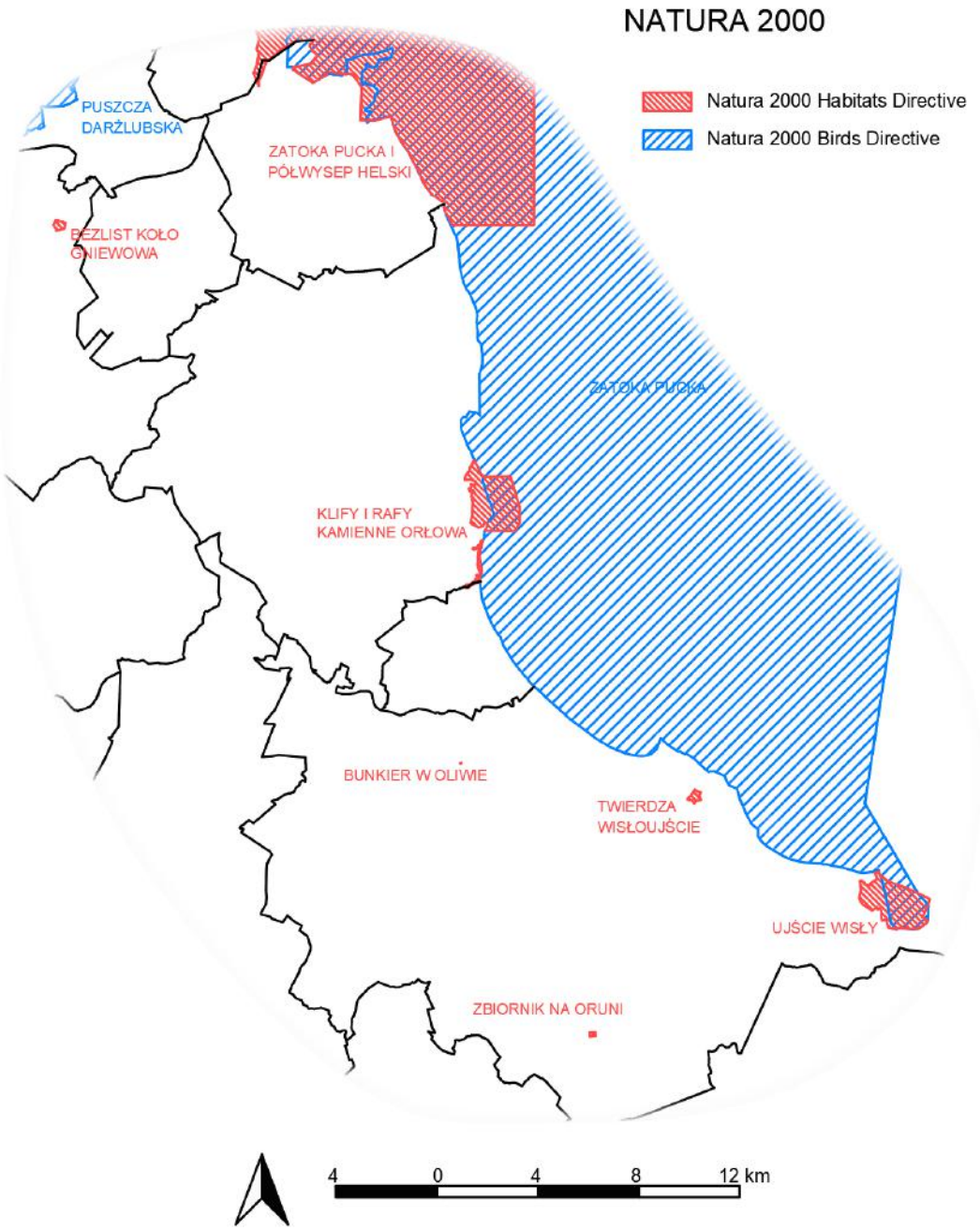

Figure 6.3. Natura 2000 protected areas in the Metropolitan Area of Tricity. Own elaboration

Another important type of protected area are ecological sites. In the analysed site, there are almost 30 such areas, some of them clustered or located near each other, so it is impossible to show them separated in the metropolitan scale. There is no need to describe all of them, in brief, they mostly protect different local humid environments like ponds, swamps, marshlands and backwaters. They are a habitat for many semi-aquatic species, amphibians or

birds. Several of them protect old buildings which are homes for bats, including Fort Nocek, which is the oldest ecological site in Pomeranian Voivodeship[12].

Last type of protected areas mentioned in this chapter are Natura 2000 areas. There are two kinds of these areas, established by Birds Directive and Habitat Directive. In the case of the Metropolitan Area of Tricity, there are two areas when it comes to Birds Directive: one connected with sea - Zatoka Gdańska, and one connected with woods - Puszcza Darżlubska.

More areas are protected under the Habitat Directive. Three of them, all located in Gdańsk: Bunkier w Oliwie, Twierdza Wisłoujście and Zbiornik na Oruni are old buildings or ruins, where great habitat have bats - great mouse-eared bat and in Twierdza Wisłoujście also pond bat. In the north of the area there is protected site Zatoka Pucka i Półwysep Helski, which covers seaside and underwater meadows of the flat gulf. In the west part of Tricity Landscape Park there is situated Bezlist koło Gniewowa, where rare green shield-moss grows. In Gdynia, the only protected sites are two parts of Klify i Rafy Kamienne Orłowa. Actually, it is quite a complex habitat, and the goals of prevention are dependent on the detailed environment: it starts by preserving the algae underwater, then maintaining the proportions between active and dead cliffs and finally keeping in good condition different types of forests. The last site is Ujście Wisły, located in Gdańsk, which is a valuable bird sanctuary.

6.6. Blue infrastructure

A bit about the blue infrastructure was written during describing the geomorphology of the area, so now is the need to expand this information. The most important water reservoir that has a huge impact on a lot is of course the Baltic Sea and actually its parts that border the site: the Gulf of Gdańsk and the Bay of Puck. The development of the whole region is dependent on the connections to the sea, but from the point of the study, very important is the net of watercourses and smaller water reservoirs.

Starting in the north, there flows the Reda River. It has its source near Strzebielino and is 51 kilometres long. In the examined area there is the middle and down part of the river, and it is easy to observe the differences between these two parts. Within the borders of Wejherowo and Reda, there courses the middle part of the river, characterised by numerous meandred and several oxbows. It makes the Reda River quite popular for canoeing. When the river starts to flow up from the town of Reda and flows into the area of Kashubian Proglacial Stream Valley, it changes its character. It joins a net of canals, from which the most important are Mrzezino Canal, Łyski Canal and Leniwy Canal. The hydro conditions of the whole area are transformed by human activity and it is used for agriculture. After flowing through the land of fields, the Reda River has its estuary among salt meadows in the coast of Bay of Puck. The river has several tributaries, but none of them is situated within the borders of the examined area.

The second important watercourse is the Zagórska Struga. It is 28 kilometres long and flows from the West Marchowo Lake. It goes across the Koleczkowo village, small colonies,

[12] *Nietoperze* [online]. Encyklopedia Gdańska. 24.09.2022, https://gdansk.gedanopedia.pl/gdansk/?title=NIETOPERZE [available: 29.09.2022]

Piekiełko and Stara Piła, which are located within the boundaries of Tricity Landscape Park, and the town of Rumia. The downriver part is located in the same site with a net of canals like in the case of the Reda River, and the estuaries of both watercourses are located near each other.

Figure 6.4. Blue infrastructure of the Metropolitan Area of Tricity. Own elaboration

The Zagórska Struga has a tributary, important from the point of the city of Gdynia. It is the Cisowska Struga, which joins the Zagórska Struga by the Leniwy Canal. It is about 12 kilometres long and also has its own tributaries: Marszewska Struga and Demptowski Potok. Each of them has their source in the Tricity Landscape Park, within the boundaries of Gdynia.

Quite short watercourse, but having significant impact on developing settlement, is the Chylonka. It is only a bit over 1,5 kilometres long, however a huge part of this small river was transformed into the harbour of Gdynia.

Moving to the south part of Gdynia, there flows the longest watercourse of the city. It is the Kacza River, which is nearly 15 kilometres long. Its source is located in Bojano near a backwater where seagulls have their nest. The watercourse flows between Chwarzno-Wiczlino and Dąbrowa districts, and then through the Tricity Landscape Park. It forms a valley, which in the west part is urbanised by the development of Mały Kack. In this section, the river is partially regulated. In its down part it cuts the south outskirt of Kępa Redłowska and flows into the Gulf of Gdańsk near the cliffs.

The Kacza River has several tributaries, the only named left-bank one is Potok Wiczliński, which has been recently recreated, as it had been dry in many places before. The longest tributary is Potok Źródło Marii, which comes across Wielki Kack and Karwiny districts, and joins the main river in Tricity Landscape Park. The last named one is Potok Przemysłowy, located in Mały Kack. It used to join a lake, which was later drained, with the Kacza River. The area in the vicinity of Potok Źródło Marii and Potok Przemysłowy will be later described, as it was chosen to be analysed in detail.

Potok Kolibkowski is the next watercourse that flows directly to the Gulf of Gdańsk. It is 2 kilometres long and has two sources. In its downriver it flows in a quite deep ravine.

The last stream in Gdynia, actually located on the border between Gdynia and Sopot, is Swelinia, 2,6 kilometres long. It has several sources and the headwater area is protected by a nature reserve. The middle part of the stream is under big urban pressure, as new settlements appear, the down river, however, flows in a wild ravine, similar to Potok Kolikowski.

As whole watercourses in Gdynia are briefly described, now is the time to present an overview of the ones in Sopot. There are over a dozen of streams in Sopot, but quite a lot parts of them are canalised, especially downrivers and estuaries. The longest ones are Kamienny Potok in the north part of the city and Karlikowski Potok in the south part. Their length equals about 3 kilometres. The name of Kamienny Potok is used also for the whole district.

In the north part of Gdańsk, the most important watercourse is Potok Oliwski. It has its source near the Tricity Bypass, estuary in Jelitkowo and is almost 10 kilometres long. Because of its significant value of slope, in the past more than 20 mills and a forge were built, which helped to develop Oliwa. Nowadays, on the stream that flows across several parks - Oliwski Park, Przymorze Park and Jelitkowski Park, there are 10 storage reservoirs.

Potok Oliwski has many tributaries, mostly left-bank. Some of them are unnamed, but an overview will be made only for the named ones. Starting with the upper part of the stream, there are Potok Barnarda and Potok Zajączkowski, which flow into Potok Oliwski near Dolina Radości, a valley with mid-forest settlement. Then, there is Potok Czystej Wody with an ecological site in its down part and Potok Prochowy, which has its sources in Źródliska w Dolinie Ewy Nature Reserve. The next one is Potok Rynarzewski, which goes across the zoo.

Finally, there is Potok Graniczny, which goes mostly underground and in the past it debouched into the sea, but it was canalised and directed into Potok Oliwski.

Locally important blue infrastructure system is the one made by streams and ponds in Ronald Reagan's Park. located in the seaside zone in Przymorze Wielkie district.

Another significant watercourses in Gdańsk do not debouch directly to the sea, but they belong to the basin of Vistula. Take Strzyża first. It is about 9,5 kilometres long and starts its course near the settlements of Kokoszki. After flowing under the Tricity Bypass, it goes through the south edge of Tricity Landscape Park and Dolina Strzyży Nature Reserve. At the skirts of the woods, Potok Jasień joins the stream. Then it goes through Matemblewo, Brętowo and Strzyża districts, with the last district sharing its name. In Wrzeszcz to Strzyża flows Potok Królewski and about 1,5 kilometres further debouches to Dead Vistula.

Most parts of south Gdańsk belong to the basin of Motława, a nearly 65 kilometres long river, whose source is in Rokickie Lake near Tczew and its estuary in Dead Vistula, to the north from the Old Town of Gdańsk. Its downriver is significantly transformed by humans, and is divided into New Motława, Old Motława and Opływ Motławy, which goes around city fortifications.

The most important tributary of Motława is Radunia. It is over 100 kilometres long and begins its course near Stężyckie Lake. In the first half of the 20th century there were several hydro-electric power stations built on it and they are still active nowadays. The river and its ravines are very attractive for canoeists and tourists. Down part of the watercourse is split to two parts: natural river, which joins Motława near Krępiec village and a 13,5 kilometres long channel, which also debouches to Motława, but near Ołowianka Island.

Radunia and its channel have several tributaries that flows through Tricity. In the west it is Strzelenka, having its source in Tuchomskie Lake and flows into Radunia near Żukowo. Other significant tributaries have their estuaries in the Radunia Channel. It is Oruński Stream and almost fully underground Siedlicki Stream.

There have to be also noted not only the flowing water, but also the lakes. Some of them were mentioned in the description of the watercourses. Main lakes of the region are situated in the west. There are Marchowo Lakes and Tuchomskie Lake, which are glacial flowing lakes. In Osowa there are two longitudinal ribbon lakes: Osowskie Lake and Wysockie Lake. In the south there is Jasień Lake, connected with Strzyża by the Jasień Stream, and Otomińskie Lake, being a kettle hole.

6.7. Functions

Some general information about other functions should be provided. In the structure of the metropolitan area there is seen the urbanised core zone with commerce functions. It stretches along the main train line, by which city trains communicate the whole Tricity. Parallel, there also goes one of the main road arteries of the area. The course of this zone begins in the Proglacial Stream Valley of Reda-Łeba and then goes collaterally to the seaboard.

The development does not appear only in the core zone. It is completed by some settlements located in the river valleys, some local upper lands and along roads getting out of the centres.

In the more peripheral sites, suburban areas develop. Partly, they arise within the boundaries of the cities, partly the villages also develop, so there appears a suburban zone with blurred borders between the city and the villages. It can be especially seen in the north of Gdynia and south of Gdańsk, where there is actually no barrier made by forests. In the case of Gdynia, the city borders in the north with the developing Kosakowo community, where in Pogórze village, located directly along the border with Gdynia, multi-family buildings rise. In other villages of this community, like Kosakowo, Dębogórze and Suchy Dwór build up not only individual detached houses, but also 'copy and paste' semi-detached and terraced houses. Gdańsk in the south borders the communities Kolbudy and Pruszcz Gdański. The whole south part of the city is currently the most developing area, where the new settlements in the districts Ujeścisko, Łostowice, Jesień, Zakoniczyn and Szadółki appear. Beyond the city border, multi and single family houses rise in Kowale, Borkowo or Straszyn.

There is also a huge suburban area in the west, behind the barrier of forests. In Gdynia there is located the most developing district - Chwarzno-Wiczlino. Far to the east, in the process of deurbanization, new houses rise in Bojano and Koleczkowo. When it comes to Gdańsk, there is some development in Osowa. The effect of urban sprawl is seen in nearby villages: Banino and Pępowo.

Main industrial zones are connected with the harbour and shipyard activitiveness of cities, both in Gdańsk and Gdynia. In Gdańsk there is also the area of the refinery.

These all functions have an impact on the green areas. The new development comes more and more nearer to the edge of the forests and the areas are under bigger pressure of human usage. Also, according to new investments, many trees and other plants are cut down, for example building Trasa Kaszubska demanded removing several pieces of woods.

7. ANALYSIS IN THE SCALE OF THE CITY

After such a detailed analysis of the Metropolitan Area, there is no need to repeat them on this scale. Actually the city would be used to see some numerical data, as boundaries of it and its districts are particular and strict. There was measured the area of forested grounds and agricultural grounds, based on the information about usage of each plot.

So, the most forested district seems to be Pustki Cisowskie - Demptowo, as it contains a huge part of Tricity Landscape Park where forests grow. Over 80% of this district are forested grounds. In the structure of the city there dominates a stripe made by Leszczynki, Witomino, Karwiny and Wielki Kack - districts also with a lot of forests of Tricity Landscape Park. In contrast, there are no forested grounds in Śródmieście and Kamienna Góra (fig. 7.1.).

When it comes to agricultural grounds, the first place goes to Obłuże and Babie Doły, because there were also counted the allotment gardens, whose main cluster is in the north part of the city. Also, quite a lot of these types of ground are still in semi-agricultural Chwarzno-Wiczlino. And again, almost no of them are in central districts: Śródmieście, Grabówek, Działki Leśne and Wzgórze św. Maksymiliana (fig. 7.2.).

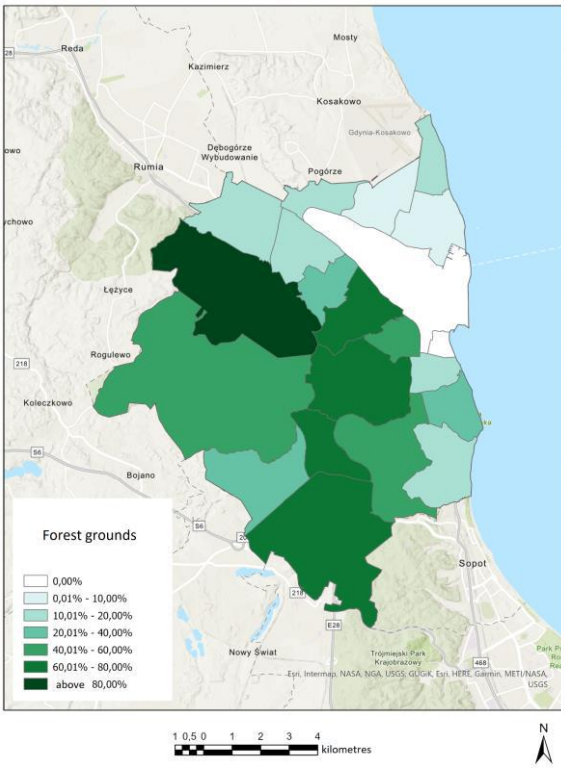

Figure 7.1. Forested grounds of Gdynia. Own elaboration

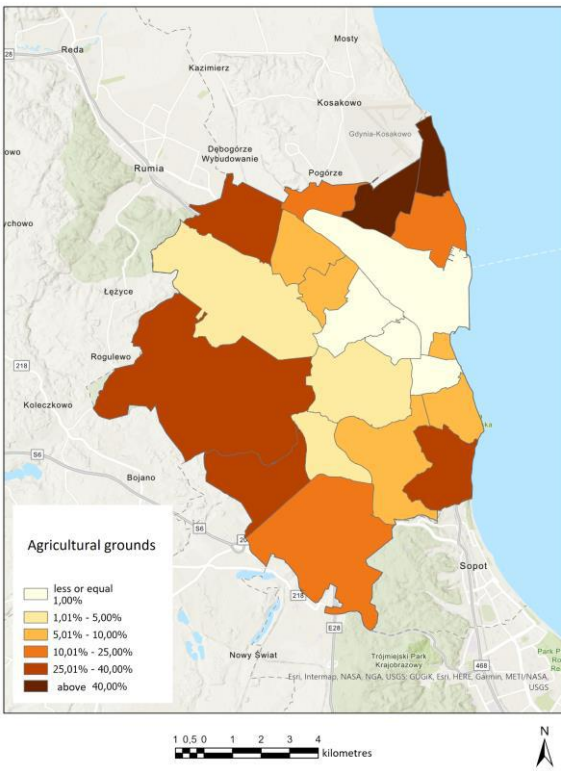

Figure 7.2. Agricultural grounds of Gdynia. Own elaboration

Before getting deeper into the analyses in the scale of the district, the site must be chosen. One of the most interesting parts from the environmental point of view is the site located between two parts of Tricity Landscape Park. At first there was delineated the area between Tricity Bypass and Zwycięstwa Avenue, and located to the south of Witomino, as it is

an urbanised area cutting the Park into these two parts. Then, from this site there was chosen another, smaller one - the west part of Mały Kack district, which is one of the most developing areas in south Gdynia. There appear new settlements in the closest vicinity of the edge of forests. Also, in the structure of the district, there can be seen some fragmented or elongating from bigger complexes parts of green areas, as well as some watercourses. That makes the site interesting and with a lot of potential.

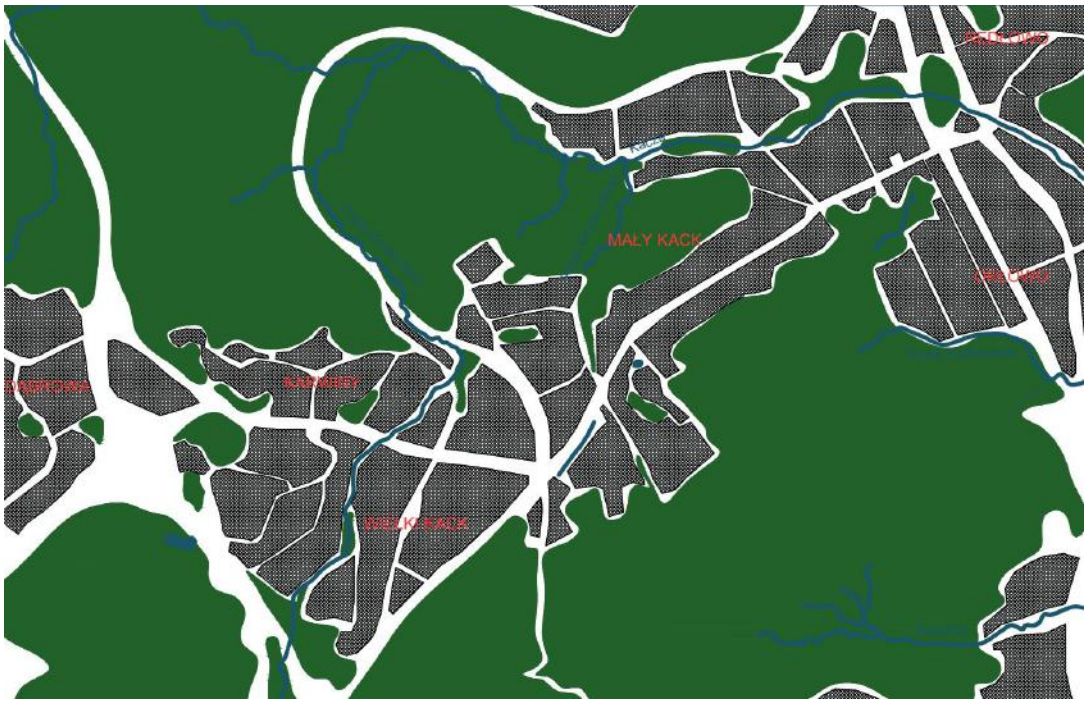

Figure 7.3. Structure of greenery in the south part of Gdynia. Own elaboration

8. ANALYSIS IN THE SCALE OF THE DISTRICT

8.1. Landform

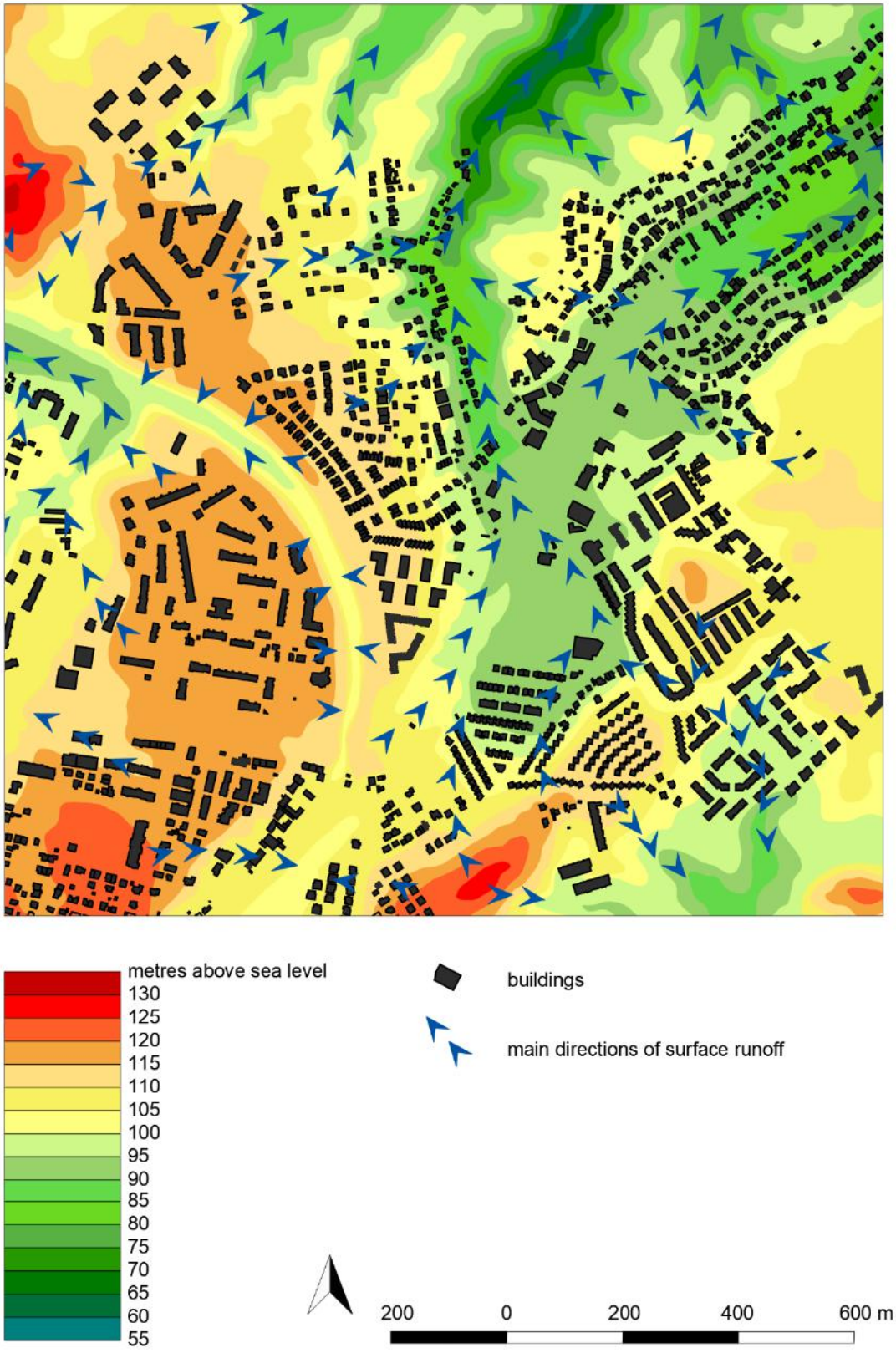

Figure 8.1. Landform and surface runoff in the chosen area. Own elaboration

The landform of the area is quite varied. The delimitations of the site, which is 2,34 square kilometres reaches 70 metres. The lowest part is located in the valley of Przemysłowy Stream, the highest - on hills on the west. As it was described in the analytical part of the Metropolitan Area, the terrain has glacial origin. In this part, there is easily observed the effect of activity of watercourses and humans. In the topographical relief there are some hollows, the natural ones, made by Potok Przemysłowy and Potok Źródło Marii, and anthropogenic ones, like a ditch for railway line. In the east part, there is a local lowland coming from glacial activity. In the north there are situated some valleys belonging to the river basin of the Kacza River. In the south, by the hollow, the rainfall goes to Swelinia.

8.2. Typology of greenery

For this analysis, the greenery was divided into several categories: forests, tall wild greenery, tall cultivated greenery, low wild greenery, low cultivated greenery, allotment gardens, graveyards, gardens by single-family houses, housing estate greenery and tree lanes.

Starting with forests, they are generally fresh mixed forests, with domination of pine and beech, but also with additives of oak, birch, spruce, larch and hornbeam. In the stream valleys there appear another type of forest, an alder forest, where more moisture-loving species, like alder, ash or elm. The age of many trees is estimated to be more than 100 years.

Tall wild greenery is represented by clusters of trees separated from forests or on the edge of them. The species may be the same as in the woods, but there may also appear the ones connected with human activitiy, like mirabelle plums, wild cherries, lilacs or elder trees. This type also has a very rich and dense level with shrubs and young trees. In the analysed area tall wild greenery appears along the railway line and Wielkopolska Street, as clusters of trees in Bernadowo settlement and at the edge of forest near Dragonów Street, Racławicka Street and Wzgórze Bernadowo Street.

The places of parks and squares with trees can be qualified as tall cultivated greenery areas. There are not many of these kinds of places in the examined area, but definitely one of them is the family park by Spokojna Street. It arises in the place of old gardens, but by the edge of the forest, so the plants are mixed. However, the dense net of paths and a lot of small architecture makes this place an organised greenery, even the lawns are nor cut down. Another example can be a cluster of trees along Wielkopolska in Karwiny, where the grass under trees is cut down regularly, but is publicly available and does not strictly belong to the settlement.

As tall greenery is described, time to move to the low wild greenery. It is represented mainly by meadows. One of them covers the area of ecological site Jezioro Kackie, where it used to be a lake, so the conditions there are good for moisture-loving species, including rushes. Only the edges of this site are overgrown by bushes and young trees. Most other low greenery areas may be potential for developers, as in the local development plans there are stated for different development. Including them there is a slope and two flat grounds in Bernadowo Hill, a slope next to Strzelców and Fizylierów Streets crossing with a gas pipe going through the terrain and a currently fenced area near Strzelców and Żniwna Streets crossing.

Figure 8.2. Typology of greenery in the examined area. Own elaboration

There is also a quite big area located on a slope in Karwiny near Nałkowskiej Street, which could be qualified as low cultivated greenery, but as it was cutting down rarer in recent years, the lawn actually became an urban meadow there.

When it comes to low cultivated greenery, the areas are located mostly along Wielkopolska Street, mainly on the belts dividing pavements and roads. According to the safety reasons, the lawns are cut down there, to make the visibility clear. However, there is not only grass growing there, as in some parts there are planted wild and groundcover roses and ornamental grasses. Also, on a bank between Wielkopolska Street and houses of Bernadowo Hill, there are many perennial plants growing.

In the analysed area there are situated two graveyards. The first of them is a municipal graveyard. It has about 6 hectares and it is the second biggest graveyard in the boundaries of the city. The second one is much smaller and it is a martial graveyard with polish and soviet tombs.

There are also two allotment gardens in the area, located on both sides of Wielkopolska Street, behind the stripes made by four or five rows of single-family houses. They are also a part of the green lungs of the area.

It should be also noted that gardens and housing estates greenery also are part of the green system. As in the area are many single-family houses, each of them has a garden with a biologically active surface. Moreover, the interiors and exteriors of city blocks are also designed with a lot of greenery. In older settlements, there are some parking places in the interiors, but in the newest ones most of the parkings are put underground, and the ones above are mostly left only where the services are.

Finally, there should be a note about tree lanes. There are not many of them in the examined site, as two of them have been recently cut down due to rebuilding roads. The first one along Strzelców Street, the second one along part of Wielkopolska Street. Fortunately, in connection with building Karwiny Nod, over one hundred trees, including oaks and lime trees, were transplanted into parks in Kolibki and Wielki Kack[13]. However, on the south edge of Wielkopolska Street and also partially in the north, there are still some parts of the lanes. Also, a tree alley of black locusts is located on Spokojna Street.

8.3. Blue infrastructure

Nearly the whole area is situated in the basin of Kacza River, and actually of its tributaries: Potok Źródło Marii and Potok Przemysłowy. Only small parts in the south belong to the basin of Swelinia and Potok Kolibkowski. Before describing the current situation of blue infrastructure of the site, there should be a look into the history.

In the east part of the current Wielki Kack district at the beginning of the 20th century was a lake called Kackie Lake. It was classified as a lobelia lake and people were fishing in it. Also, the lake was joined with Potok Źródło Marii by a small stream flowing from south-west

[13] *Drzewa z węzła Karwiny w bezpiecznej przystani* [online]. Serwis internetowy Miasta Gdynia. 19.08.2020, https://www.gdynia.pl/dla-mediow/komunikaty,4100/drzewa-z-wezla-karwiny-w-bezpiecznej-przystani,551285 [available: 29.09.2022]

edge of the lake. In the hydrographic net of the area this stream is still seen. However, in 1905 the lake was drained and the area was changed into pastures. The waters from the lake were transported to Kacza River by the canal, which later was called Potok Przemysłowy. In the 20s the site was flooded, because the canal was choked and the lake came back, but it was drained again, as the water might be dangerous for a rising railway line. In subsequent decades the site was flooded many times. The lake appeared for the last time in the late 70s, when the canal was choked again, and for several years the reservoir was a local tourist attraction, with a possibility to rent a boat[14]. As it still can be dangerous for tracks, in 1983 tha lake was ultimately eliminated. Now it is a swampy area, very rich in respect to biodiversity. For example, it is often possible to see common cranes here.

On the analysed site is placed nearly full Potok Przemysłowy. As it flows from Kackie Lake, it goes under Sopocka Street and then parallel to Wielkopolska Street, behind a bank that separates it from the main street. The stream bed is almost not visible here and could be identified only by small channell and moisture-loving plants in some places. Then, near the crossing with Racławicka Street, the watercourse goes under Wielkopolska Street and flows underground in all length of Racławicka Street. It used to go parallel to this street on the ground, but at the beginning of the previous decade the street was rebuilt and in the place where the stream was flowing, the pavement was built. When Potok Przemysłowy reaches the edge of the forest, it finally escapes from underground and by a natural bed with some meanders goes across the valley for nearly a half of a kilometre. Its last 200 metres are covered with concrete and it flows into Kacza River near a playground and a football pitch.

The other watercourse situated on the site is Potok Źródło Marii. Only a short part of its middle section actually is in the analysed area. On this part there is a dry storage reservoir. The stream goes parallel to the railway line, as it was easier to build this kind of infrastructure in the valley than through the hills.

There are also two ponds located in the area, one near Spokojna Street and one near the crossing of Strzelców Street and Fizylierów Street.

8.4. Functions

In the area the main function is housing. The whole Mały Kack is considered to be mostly a single-family housing district, with a lot of detached and semi-detached houses from the 50s and 60s. However, on the map there are seen some multi-family buildings, mostly in the peripheries of the district. Most of the new settlements appeared in the last two decades in the place of fields and meadows.

[14] Gajos D.: *Jezioro Kackie - bogactwo przyrody w środku miasta* [online]. Muzeum Miasta Gdyni, https://muzeumgdynia.pl/2022/05/jezioro-kackie-bogactwo-przyrody-w-srodku-miasta/ [available: 29.09.2022]

Figure 8.3. Functions of buildings located in the examined area. Own elaboration

Along Wielkopolska Street there are located quite a lot of services. Many of them are connected with car repairing and there are several car showrooms, two petrol stations and a

car wash.. Near the graveyard there are gravestone carving services. Local centres of commerce are situated in three places where main retail services are gathered: around a discount retailer in Wzgórze Bernadowo, along the services on ground floor along Strzelców Street and around two discount retailers and a small market in Karwiny. In the area there are also several kindergartens and a church.

8.5. People movement

As it was written above, through the area courses one of the main streets of the city, Wielkopolska Street. It goes above the railway line with Karwiny PKM Station. Just right to the station, the street crosses with Strzelców Street, which leads to multi-family housing settlements, and Sopocka Street, which is the easiest way to get to Sopot. This crossing is currently under reconstruction, as it is a very important local node, so it requires some more effective solutions than the ones that were used until now. The PKM Station enables people to the airport in Gdańsk and centres of both cities. On Wielkopolska Street shuttle over a dozen bus and trolley bus lines. In addition, one bus line gets to the end of Strzelców Street, one rides on Spokojna Street to the surroundings of the graveyard, and one daily and one night line apply on Sopocka Street.

Shortly analysed transport system indicates that the area is very well communicated. More important question is how people use green areas and where are the main directions of movement connected with this kinds of areas. The most attractive green areas in the site are the ones connected with two forest complexes protected by the Tricity Landscape Park. Take under analysis the north complex firstly.

On the other side of the forest there is located a lower part of Mały Kack, so the paths are used as shortcuts. For example, to get from Racławicka Street to Płocka Street, there is a need to cross less than one kilometre by foot, and about three kilometres by car. Of course, the woods are attractive themselves, and they are often used by walkers, cyclists, owners of dogs or mushroom pickers. By the paths, that partially go in the valleys of streams, it is possible to get to the Kacze Łęgi Nature Reserve and attractions next to it: Krykulec glade with potential picnic place and a storage reservoir, and a detritus of old forester's lodge, currently with a bats habitat. Also, near the edges of the forest there is a system of self-made paths for BMX bikes.

Along Racławicka Street there is an arm of greenery, connected with the bigger complex in the north. On its terrain, there are three playgrounds that are often visited not only by the inhabitants of nearby houses, but also by the residents of multi-family houses from Strzelców Street, who get there mainly by Grenadierów Street.

Figure 8.4. Communication in the examined area. Own elaboration

In the south one of the biggest attractors is a new family park located by Spokojna Street. The park is still under development, but it brings people from surrounding settlements and even farther parts of the district. There is situated a dog run, a small amphitheatre, some hammocks, and there is planned a track for BMX bikes. Next to the park there start some paths that lead to Orłowo and Sopot. They course across a mosaic landscape of clumps of trees and old gardens, and on them there are located many points that can be destinations of shorter or longer walks. Among them, there is a raspberry plantation with a modern self-service shop, where it is possible to get fruits and preserves, an observation tower in Kolibki, a shooting range, a stable in Bernadowo and Łęg nad Swelinią Nature Reserve. In the south-west part of the site there is Kackie Lake, by its edge there is an option to get deeper to other parts of Tricity Landscape Park.

As in the analysed area there are allotment gardens, it should be also noticed that people move to them. Owners of the gardens are mixed - they are both the inhabitants that live just right next to their garden, as well as the ones who have to get there from other districts or even cities. The gardens are fenced areas, so the movements are focused to several gates which each garden complex has.

8.6. Interventions in green public spaces

There were examined prizewinning projects from the last five editions of participatory budgeting, that are connected with greenery and climate, and were or are being realised in the vicinity of the chosen area[15].

In the 2021 edition of participatory budgeting in Gdynia there was organised a special category of city climate budget, and that year won the projects of recreating tree lanes and planting low greenery along the main streets of 7 districts of Gdynia. Among them are Karwiny and Wielki Kack. In Mały Kack from this year there are new plantings in the family park and one of the crossings. In Orłowo, there is planned a new city orchard in the place of wild greenery. In Wielki Kack, there appeared a new intergenerational park next to Stolemów street. There was also chosen a gauge measuring the quality of air.

In 2020 in Karwiny there won a complex project of realising among others a pocket park near Staffa Street and plantings of roses and red grass in Brzechwy Street. In Mały Kack in that year, the family park was expanded and the first phase of new plantings on one crossing was chosen. A neighbourhood garden next to a wild orchard and plantings of flowers and trees on Plac Górnośląski won in Orłowo.

Realising pocket parks in 9 districts was a winning project in 2019 in a city category. Among them, there was a pocket park in Wielki Kack. What should be noted, also that year there was advanced a project of several rain gardens located on bus loops, as well as a project of urban meadows in 9 districts, however they did not win. In Mały Kack, this year was the

[15] Budżet Obywatelski Miasta Gdyni. Poprzednie edycje [online]. Strona Internetowa Miasta Gdyni, https://bo.gdynia.pl/poprzednie-edycje-2/ [available: 28.11.2022]

beginning of rising a family park along Spokojna Street and in Orłowo there was planned to straighten a wild orchard.

8.7. Examination the urban heat island effect

8.7.1. Selection of the points

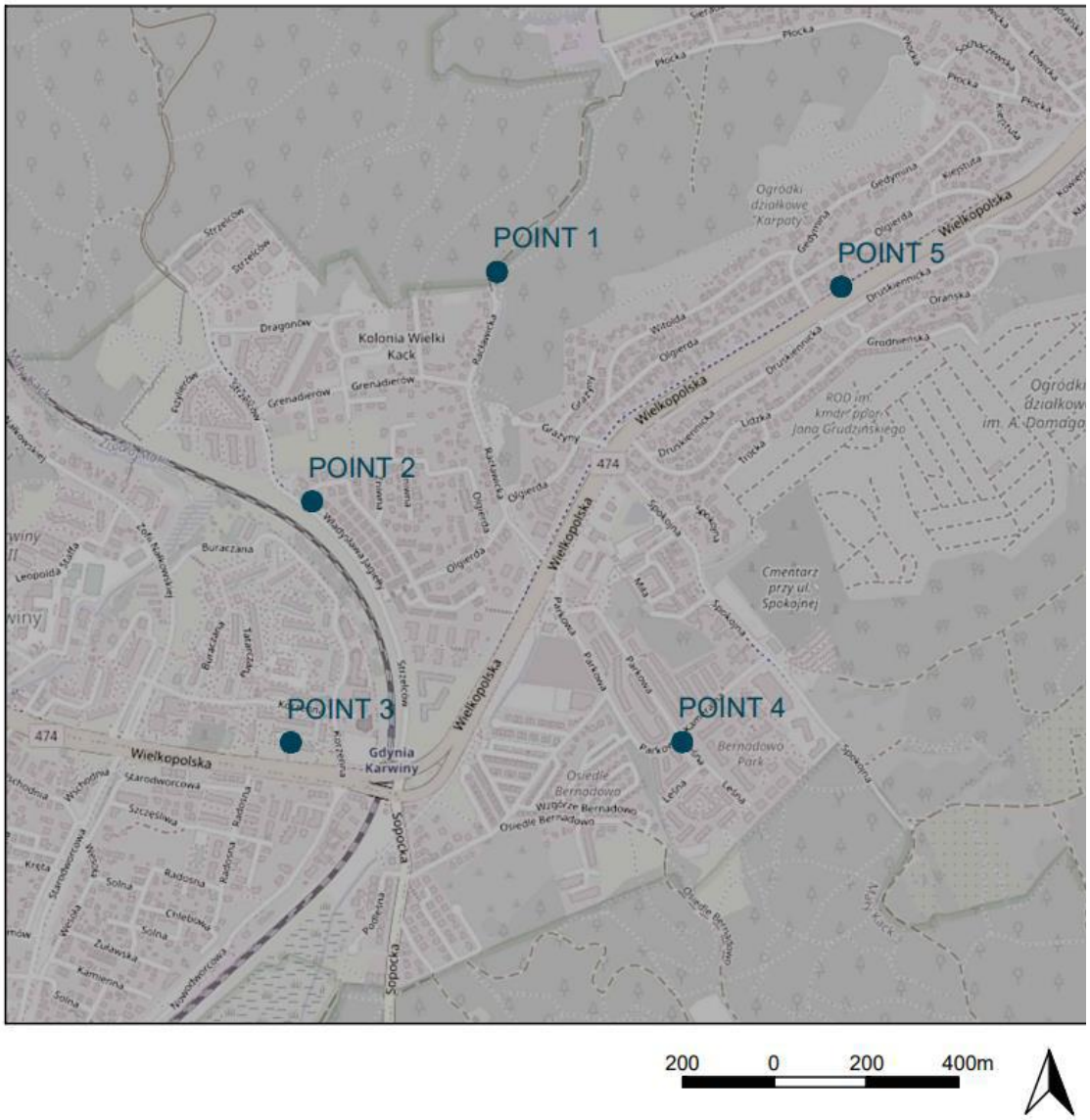

Figure 8.5. Map with the location of chosen points. Own elaboration

To see the urban heat island in the local scale, there were taken own measurements of temperature in several parts of the area designated in the district scale. There were five points chosen with different conditions. The temperature was measured for three days, three times each day - in the morning, in the afternoon and in the evening. Also the was measured four kinds of temperature - air temperature in the sunlight, air temperature in the shadow, ground temperature in the sunlight and ground temperature in the shadow. As the most reliable results

are reached by measuring air temperature in the shadow, these measurements describe weather conditions, and could be easily compared to the ones presented in the local weather forecast. However, humans also perceive other types of temperature, that is why they were also taken into account. The location of the points is presented on the figure 9.6.

The first point is situated at the edge of the forest, on a slope of Przemysłowy Stream, a small watercourse which is a tributary to Kacza River. The temperature was measured at the altitude of about 70 metres above sea level, in the shadowed grass in the closest vicinity of the stream, as well as in the heat forest cover on the east-exposed slope.

Figure 8.6. Point 1 - east-exposed slope in the sunlight. Own photo

Figure 8.7. Point 1 - Przemysłowy Stream. Own photo

The second point is located only about 600 metres in the straight line from the first point, but nearly 50 metres higher - at the altitude of 116,5 metres above sea level. This place is a crossing in a single-family housing neighbourhood next to a train line. Until recently there was a tree lane, but unfortunately it was cutted down due to rebuilding the street. The temperature on the surface of the soil and the asphalt was checked.

Figure 8.8. Point 2 - street without tall greenery around. Own photo

Figure 8.9. Point 3 - an interior of an urban block with a playground and some greenery. Own photo

The next point is the only point located in Karwiny district. It was chosen, as there are multi-family houses from the 80s,and there are no such buildings in Mały Kack. The selected area was a green interior of an urban block building quarter with a playground on the altitude of 119,5 metres above the sea level and there was measured the temperature of grass under bushes and of pavement brick.

A street crossing in Bernadowo Hill was chosen as the fourth point. This crossing is surrounded by relatively new multi-family houses and it is situated at the altitude of 103 metres. Similar to the previous point, the temperature of ground under a tree and of pavement was checked.

The last point is located on Wielkopolska Street, next to the 'Olgierda' bus stop, the one in the direction of Karwiny. The street is one of the main streets of the city and the core of the functioning of the south districts of the city. The altitude of this point equals 75,5 metres above sea level and the thermometers were put on the surface of pavement brick and grass under a bush.

Figure 8.10. Point 4 - a crossing in a new settlement with not much greenery. Own photo

Figure 8.11. Point 5 - the vicinity of the bus stop 'Olgierda'. Own photo

Before presenting detailed results of temperature measurements, there should also be described general weather conditions during the three days of research. Although it was conducted in July, the temperature was 27 degrees and generally was fluctuating between 16 and 21 degrees.

Important factors that influenced the temperature were the percentage of cloudiness of the sky and the humidity, assessed by the presence of rain, and how they were changing during the days. The first morning was quite sunny, however, the later it became, the more clouds came into the sky, with almost no sun in the afternoon. The second day started similarly, however at noon, there occurred a heavy rain, and then during the afternoon research it also rained twice lightly. The beginning of the third day was like the previous two days, so it could be said that all three mornings were sunny. However, in the afternoon it was also raining and the sky was fully clouded.

What should be also noticed, the hours of measuring temperature in the evening took place after sunset, except the second point, which is west-exposed, and last rays of sun reached the ground during the research. In other cases, when the temperature in sunlight is presented, it was actually measured at the place that was exposed to the sun during the day.

8.7.2. Measuring temperature in the same places but in different conditions

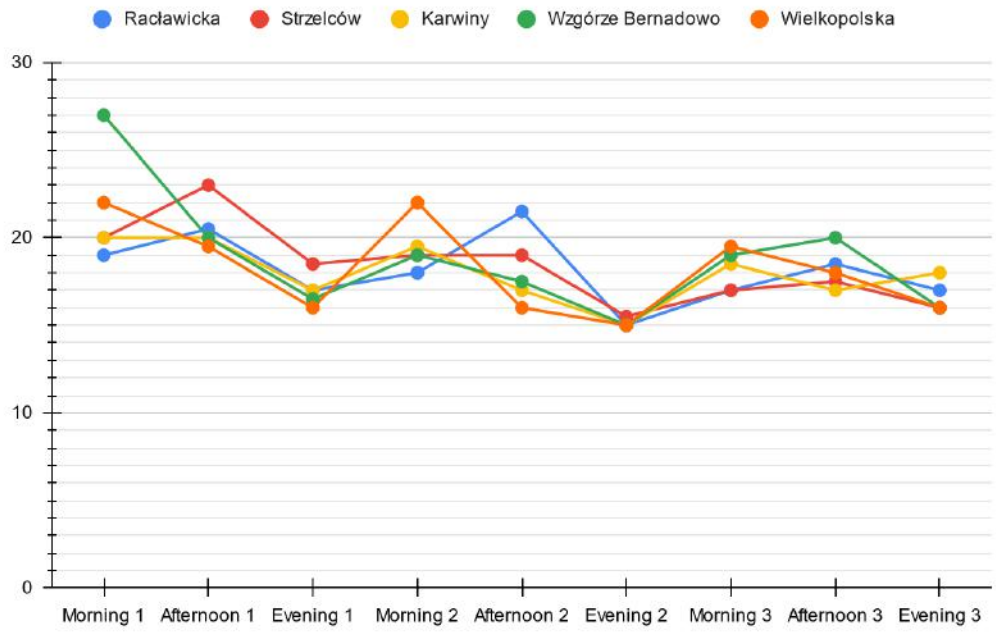

Figure 8.12. Temperature of air in the shadow. Own elaboration

Now, the results between different points will be compared and the temperature of air in the shadow will be taken into account firstly. The highest temperature was measured on the first morning in Wzgórze Bernadowo with the value of 27 degrees and the lowest - in the second evening with the same value of only 15 degrees in all points except Strzelców. Interestingly, the highest temperature in the second afternoon was in Racławicka, the most natural point, and in more urbanised ones it was lower. It indicates that the rain, which appeared that afternoon, decreased the temperature in the more build-up areas.

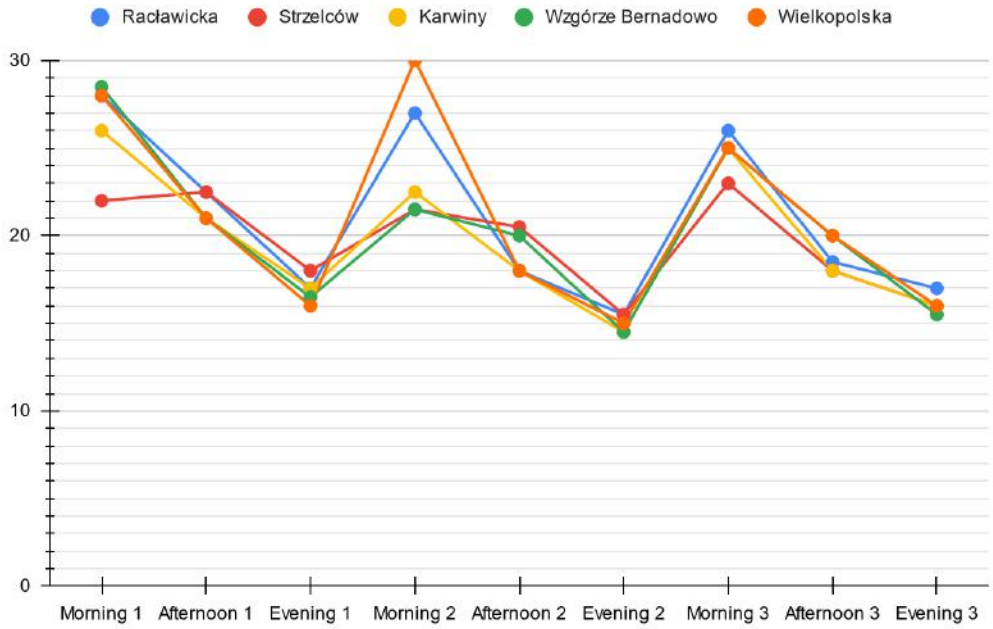

Figure 8.13. Temperature of air in the sunlight. Own elaboration

When it comes to the results of measurements of air in the sunlight, the amplitudes become bigger. The highest value equals 30 degrees was noted in Wielkopolska in the second morning and the lowest - only 14,5 degrees in Wzgórze Bernadowo in the second evening. The largest amplitudes took place in the first and second morning, according to the influence of the sun.

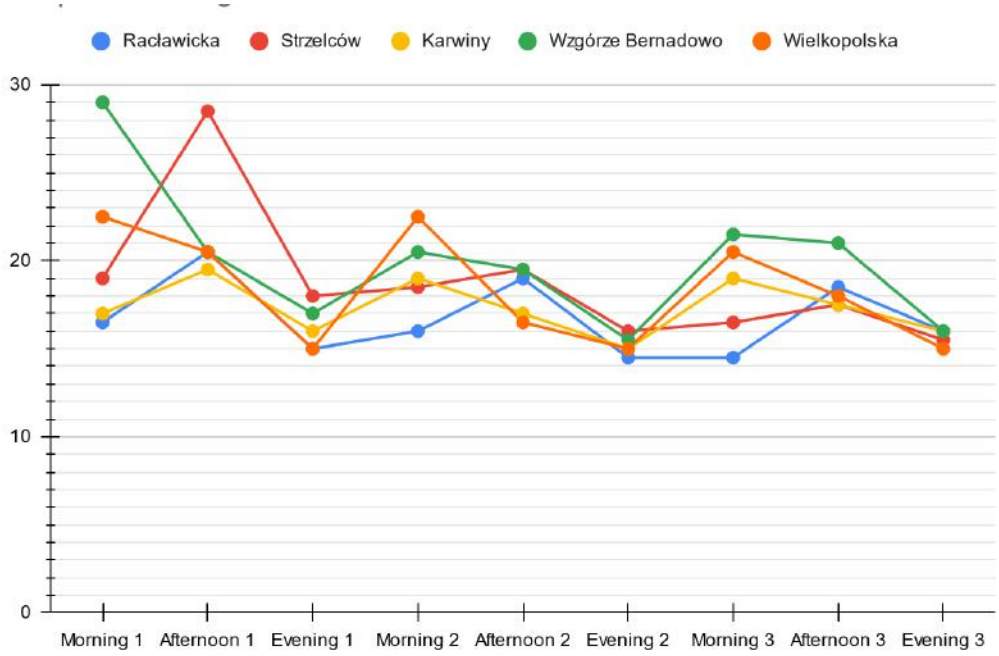

Figure 8.14. Temperature of ground in the shadow. Own elaboration

Very interesting results came when the thermometers were put on ground. The material of each ground was different in different places, but it was chosen the most dominating one. During the research of the temperature of the ground in the shadow, there were chosen the places where the shadow was almost all over the day, like under the bushes etc. However, it was impossible in point 2, as there is not such a place - in any specific place the sunlight came for at least several hours, that is why the results might be disrupted.

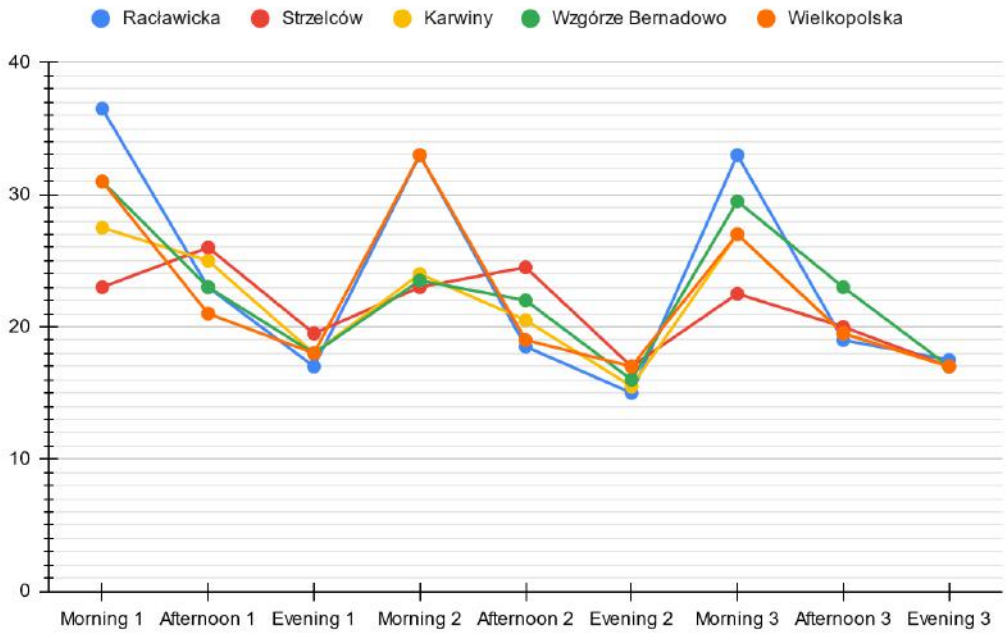

Figure 8.15. Temperature of ground in the sunlight. Own elaboration

Finally, the temperature of the ground exposed to the sunlight was measured. Surprisingly, the highest temperature was reached every morning in point 1. The forest cover located on the east slope preheated during the mornings even to 36,5 degrees. On other parts of days, the temperature in other points was higher, but as it was described above, there were not many sunny days, so the value rarely passed the level of 30 degrees. But what should be also noted, the amplitudes of the temperature of ground in sunlight are bigger than the ones in shadow.

8.7.3. Mapping the results of measuring the temperature of air in the shadow

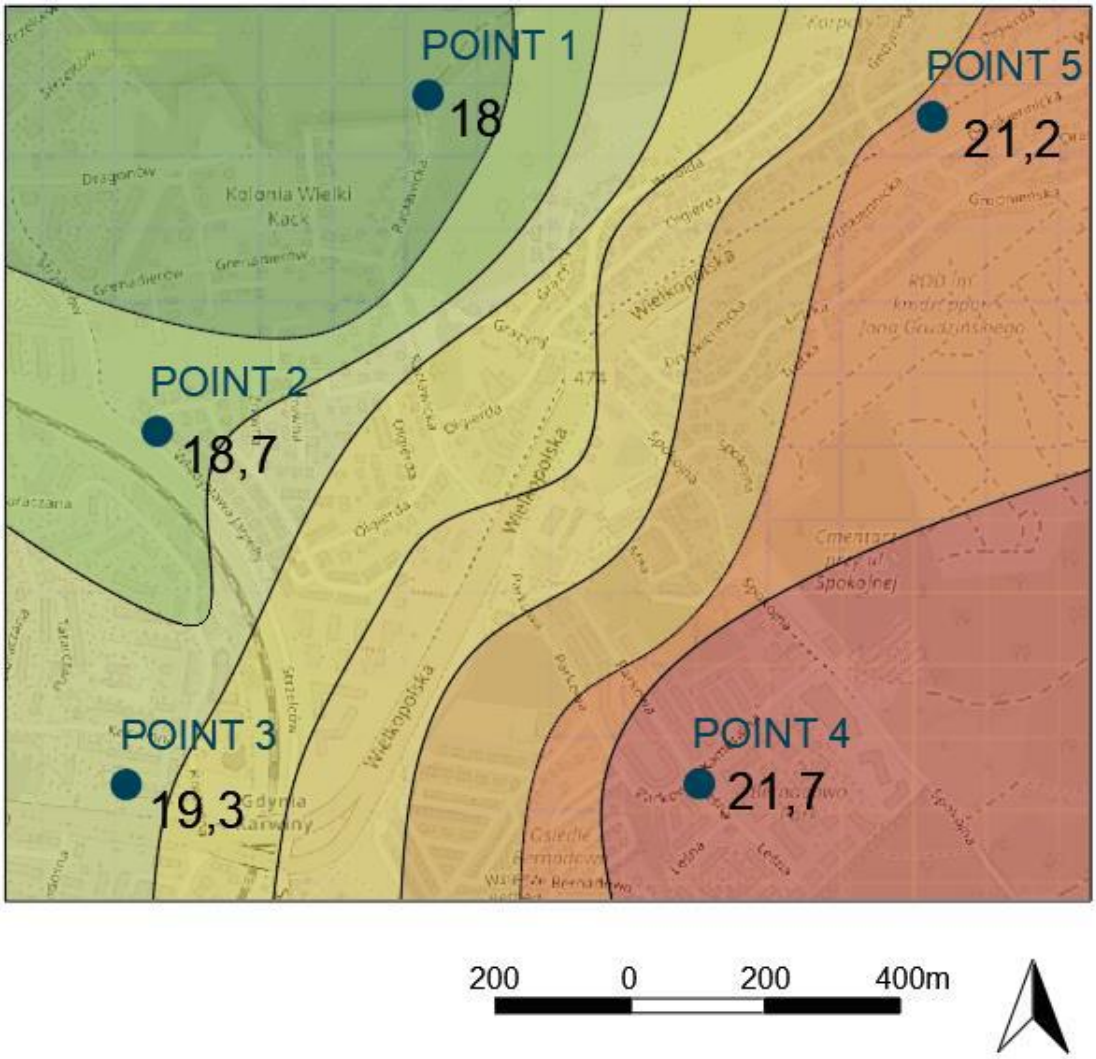

Figure 8.16. Map with the average temperatures gathered from all three mornings of examination. Own elaboration

The results of measuring temperature in the mornings are present in the figure… The amplitude between different parts of the site are very high and reach 3,7 degrees. The coldest part is the north-west corner, where the forest valley was examined, so it is not surprising - the big complex of greenery cools down the temperature. The hottest was crossing in Bernadowo Hill, surrounded by housing estates.

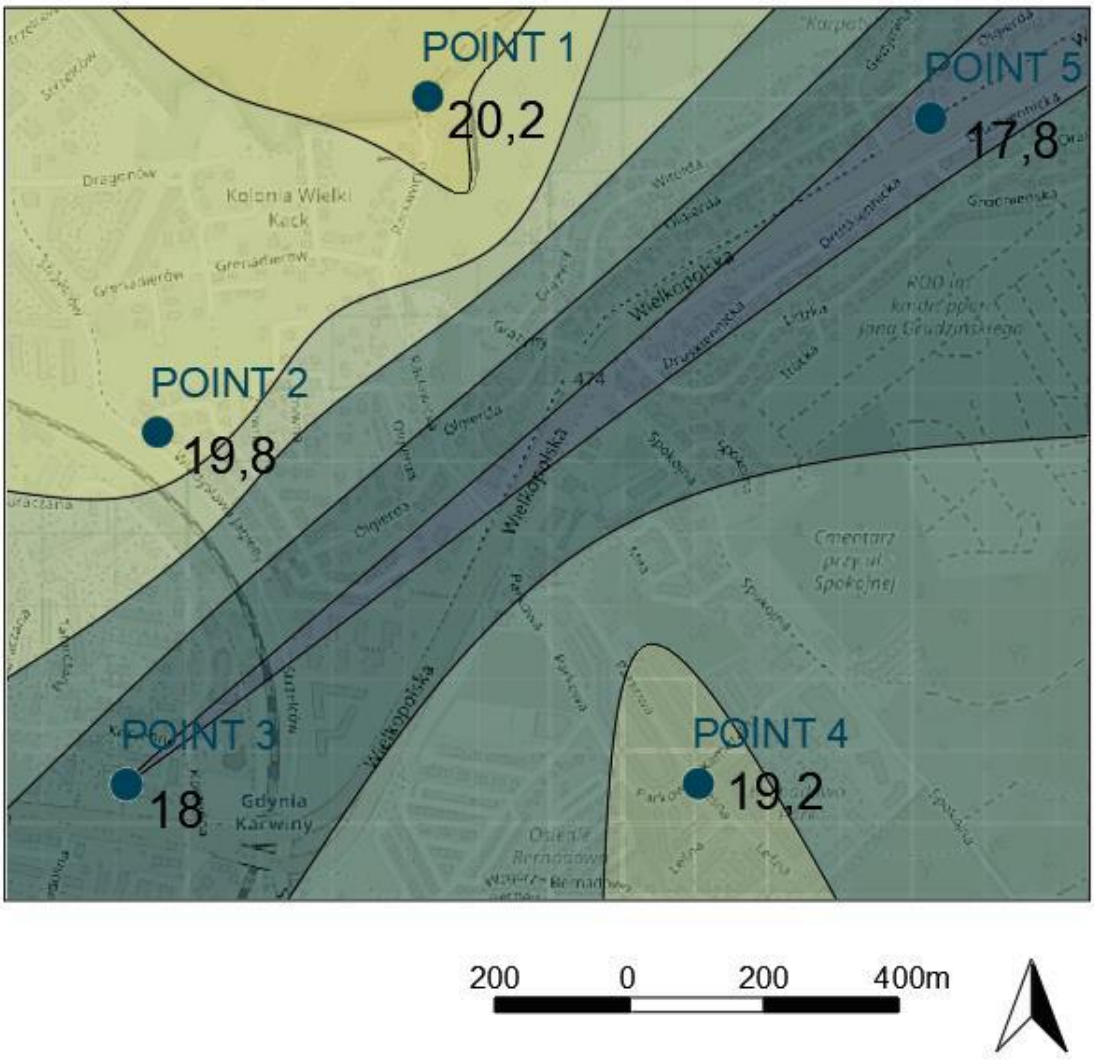

Figure 8.17. Map with the average temperatures gathered from all three afternoons of examination. Own elaboration

The average temperature of three days in the afternoon was cooler than in the mornings. It reached maximum 20,2 degrees, and what definitely should be noted, it was reported in the forest valley. There could be a conclusion that the forest gathered the heat during the sunny mornings, and kept it during the cloudy afternoons. Also in Bernadowo Hill the temperature was quite high. The lowest results were in Olgierda bus stop and in Karwiny, which yielded in a cold corridor along Wielkopolska Street on the map.

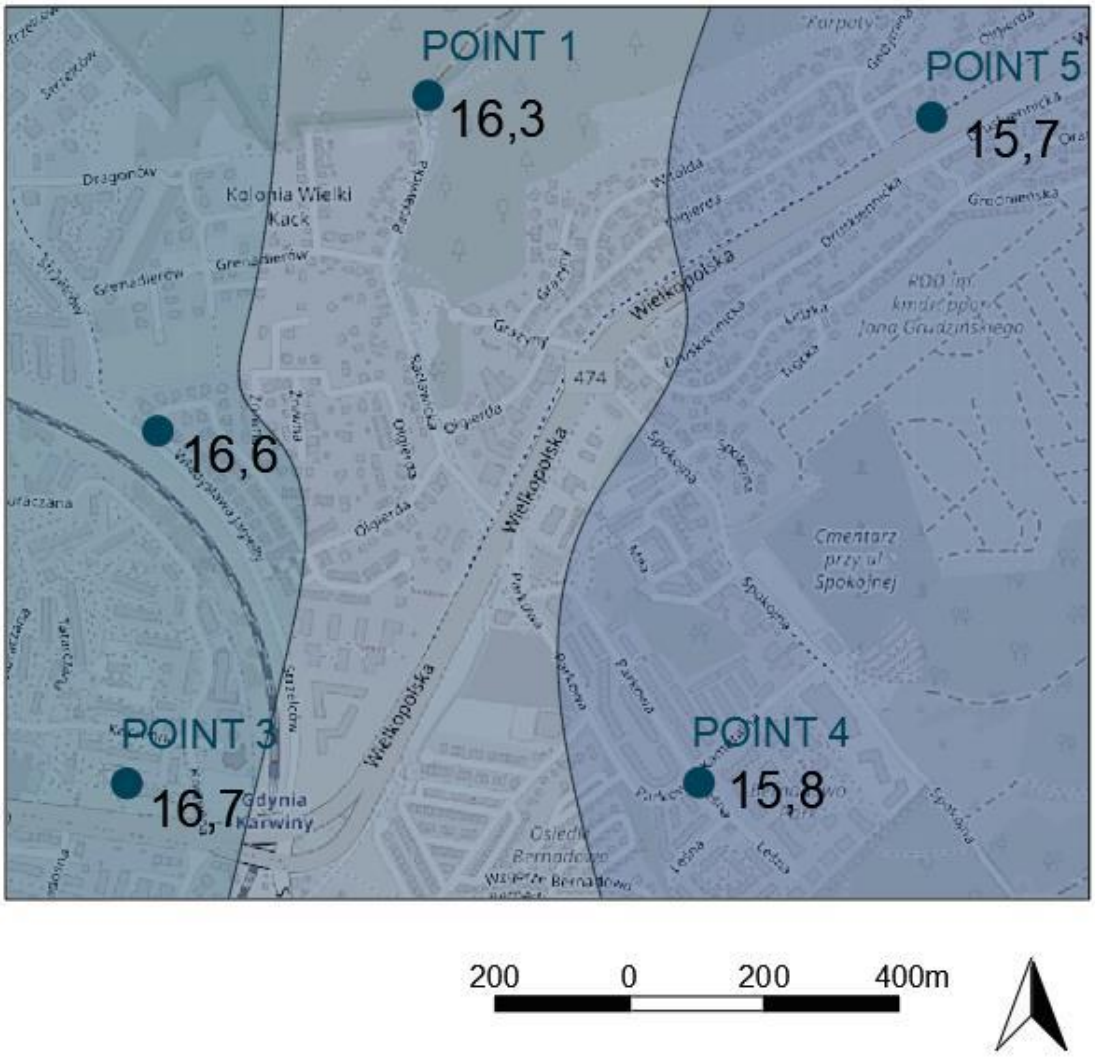

Figure 8.18. Map with the average temperatures gathered from all three evenings of examination. Own elaboration

Finally, the amplitudes in the evening were the lowest and reached only one degree, so the differences are getting blurred. The hottest were the west part, which is the longest exposed to the sunlight.

8.7.4. Conclusions

The conducted research showed that the problems with local urban heat island may occur in the site and, what was quite surprising, sometimes the differences in temperature between particular places are high. The phenomenon appears not only in the scale of the whole city and is not only connected with dense urban structures of city centres, but also appears in more suburban or located directly to big complexes of forest areas. Types of buildings, distance to green area, height above sea level or sunlight exposure change the conditions significantly.

As a result, humans perceive these conditions differently and may be vulnerable to the changes that appear. Even if there seems to be a lot of greenery, there is still a reason to implement more blue and green infrastructure here, which would help to mitigate the effects of climate change.

9. ANALYSIS IN THE SCALE OF THE NEIGHBOURHOOD

Two sites were chosen for the most detailed analysis, as their structure would be important in the design part.

The first chosen site, site ‘A’, is situated in the north at the end of Strzelców Street. There are fenced settlements clustered in three areas. In the north there is a settlement ‘Apartamenty na Polanie’ where the buildings are dispersed. There are eleven 7-storey buildings, of which five are built on the shape approximate to square and the rest - approximate to rectangle with the area nearly twice bigger than the square ones. What is important, this settlement seems to be very green, as most of the parking places are put underground, so there are a lot of plantings in the spaces between buildings, and pavements are only put where necessary. When it comes to tall greenery, there are only two trees planted inside the estate, but in the north-west and north-east the site borders directly with the forest, and in the south a belt of trees separate it from other urbanised areas.

Moving to the south, the next estate is located in an urban block in the shape of an irregular pentagon and consists of six buildings. In this case, the parking places are also put underground, there are just some situated outside the urban block which are on the open air, but there are not any inside. However, the interior of this estate is less greener than the first one. A lot of the area is paved.

The last estate, located on the other side of Strzelców Street, could be actually subdivided into two parts. The first one is also a fenced urban block, located in the shape of an irregular quadrangle, whose components are four buildings. In the south there is a complex of three longitudinal buildings and a one that was built later. There is also a lot of designed greenery inside the urban block.

The second site, site ‘B’, is located in the south. At first glance it seems similar to the first site, however there are some differences in urban morphology. As in site A the three settlements are clearly visible in the structure of the city and are located separately, in site B the particular settlements are located just right next to each other. However, the shape of the buildings and their composition allow recognition of several groups of buildings.

The development appeared generally in four main stages. The oldest ones are the buildings seen on the north, along Spokojna Street, characteristic for most part of Mały Kack. After 1990 the area started to develop and new settlements came up. In the second phase there appeared single-family houses of Osiedle Bernadowo, situated on the west. The next was Cadena Park, an estate located along Parkowa Street, consisting of four 3-storeys buildings and one 4-storeys building with an active ground floor. On the map there are present only three buildings.

Figure 9.1 .Inventory of site ‘A’. Own elaboration

The newest realisations are two settlements that are still developing are Merano Park and Bernadowo Park. Merano Park is a complex of fifteen 2-storey buildings, in which there are located terraced houses, from four to seven in each building. The walls and roofs are fully white. On the opposite side of Kameralna Street, there is Bernadowo Park, the largest of the described settlements in this site. It consists of ten closely to quadrangle shaped buildings and seven longitudinal buildings with four floors and sheer roofs.

Figure 9.2. Inventory of site ‘B’. Own elaboration

10. DESIGN - ADDING MORE GREENERY TO THE DISTRICT

10.1. Potential green connections

Between different, smaller or bigger complexes of greenery, there were proposed several new connections, which would help to strengthen the green infrastructure, presented on the figure 10.3. The aim is to create a net of greenery, like for example green corridors in Stuttgart (fig. 10.1.).

The one marked on the map with yellow, would be the connections in the city scale, as it would be implemented along Wielkopolska Street. There is the potential in green belts located on both sides and partially in the middle of the street, to have more plants to grow there, especially trees. The idea of this connection is to create a green road and complete some existing tree lanes - young ones made by oaks planted in the last few decades with older ones, located on the part on the border of Mały Kack and Orłowo, where lime trees grow.

There are also three proposed connections in a district scale. The first one would join areas of greenery that are situated along two watercourses: Potok Źródło Marii and Potok Przemysłowy. Between them, there are many still undeveloped plots, so appropriate design of them might result in more greenery. There is a barrier made by the railway line, however there is planned to be a bridge for pedestrians and cyclists over the line, but it would be still hard to make a direct connection in this place when it comes to green areas. On the side of the tracks in Mały Kach, there is a 2 hectares undeveloped area, where there is planned to be realised a public service with a pitch, so it would be good to plan a park around. The park would smoothly join Grenadierów Street by some empty plots, and along the street there would be planted more trees. The street crosses with Racławicka, where the existing green area begins.

The second connection in district scale would join the areas on both sides of Wielkopolska Street. There is a potential in Spokojna Street, because there are some existing tree lanes made by old black locusts and a space for some new plantings along the street (fig. 10.2.).However, there might be some problems in implementing similar interventions in Grażyny Street, as there is not so much space. But if the connection appears, it would join the north part of Tricity Landscape Park with the family park in the south, and then with the south part of the landscape park.

Figure 10.1. Green corridors in Stuttgart. Source: Google Maps

Figure 10.2.Tree alley on Spokojna Street. Own photo

The last connection in the district scale would be the greenery along Strzelców Street. It would help join the new park through the multi-family housing estates with Tricity Landscape Park in the north.

Figure 10.3. Map with new proposed connections between green areas. Own elaboration

There would be another connection in the district scale, but it is classified as a connection based on the blue infrastructure. The aim of it would be to strengthen and clear the course of Potok Przemsyłowy, as it is actually a connector between two important elements of blue infrastructure - Kackie Lake and Kacza. As some part of it goes underground, a possible idea is to recreate it over the ground. However, there was made the analysis, that this watercourse is partly artificial made and plays its role well like it is now, and also one part of it was over a dozen years ago just put under the ground, to make a pavement along Racławicka Street. So the proposal is just to focus on green infrastructure above the ground and add more greenery in the place where this stream goes underground.

The last category of connections are the local ones. The first one would start in the greenery next to the graveyard, go through the clamp of trees located on a hill and join a belt of greenery along Wielkopolska Street. The next one will be a connection between the family park in Spokojna Street to a stripe of trees in Bernadowo Hill across the urbanised area, where there is also planned a link to the clump of trees mentioned above.

10.2. Improvements to buildings and surfaces

The design part establishes some transformations in existing buildings. As it was mentioned in the part describing the phenomenon of urban heat island, a strong role in cooling temperature play green roofs (fig. 10.4.). In retention helps a more biologically active surface, so a good practice is to recover it from the paved surface where it is possible. Finally, the design should not only take into account the horizontal surfaces, but also the vertical ones, so in case of greenery, the green walls would be implemented (fig. 10.5.). These solutions would be used in two sites with multi-family housing settlements chosen from the area.

Figure 10.4. Green roof in Warsaw. Source: Maciej Fijak, https://smoglab.pl/ogrody-buw-20-lat/

Figure 10.5. Green wall on a building in Mokotów, Warsaw. Source: M. Wiśniewska-Krasińska, Archiwum FNP, https://magazyncieplasystemowego.pl/miasta-przyszlosci/ogrody-na-scianie/

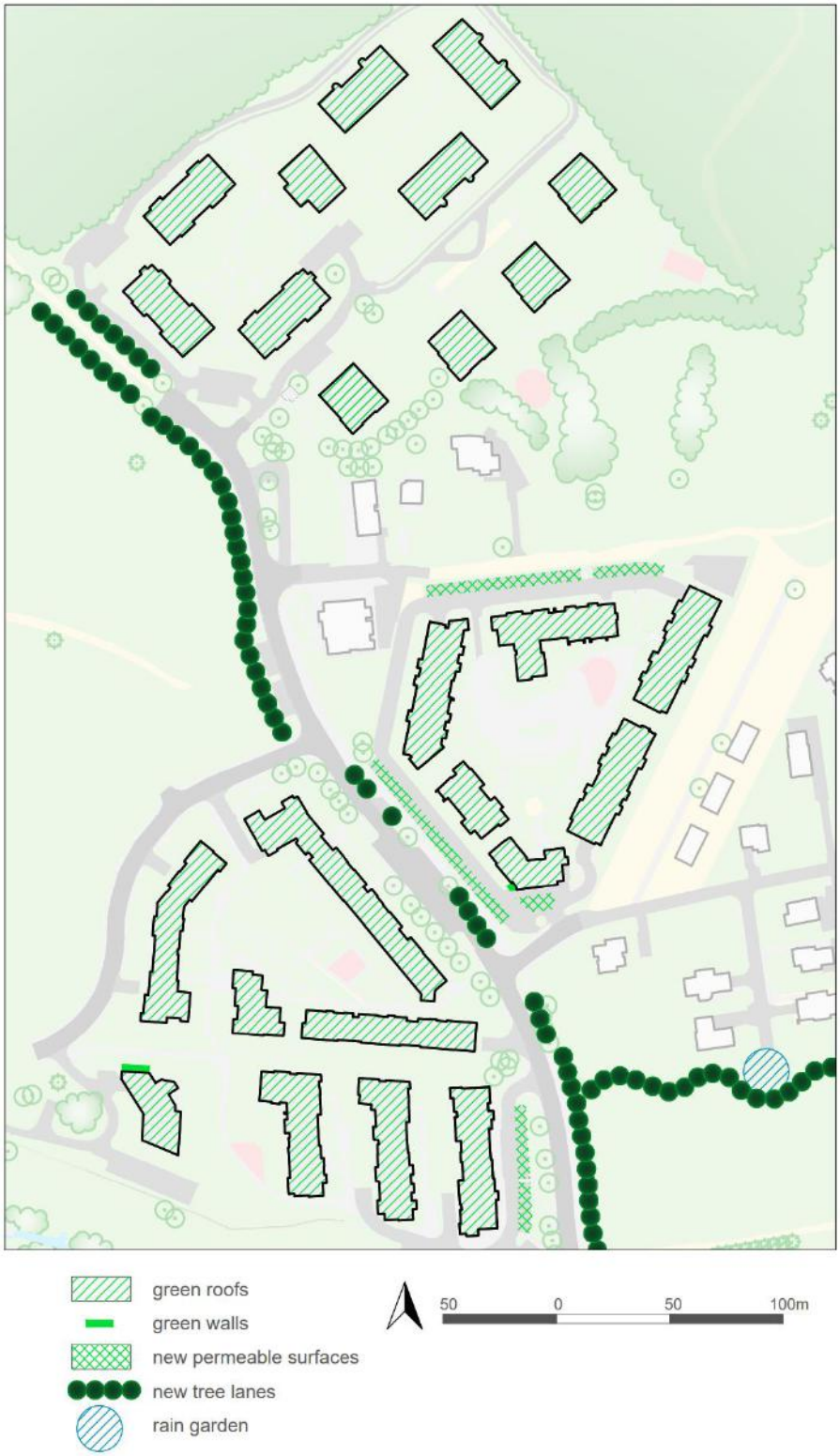

Figure 10.6. Project of implementing green solutions in site ‘A’. Own elaboration

However, even at a site so rich in greenery, it is still possible to improve it. In this case, as the roofs were checked, all multi-family houses have flat roofs, so there is an option to locate on them green roofs. Take site ‘A’ at first (fig. 10.6.). Together, there would be 25 buildings with

green roofs. There is one important thing to be checked before designing such roofs - the load of each building should be measured, to decide if there is a possibility to build an intensive green roof there.

Another solution related to buildings is a green wall. There were searched walls with no windows, where such a wall could be easily implemented. In the analysed area there were only two walls identified - one in a new building in the south, second in a quite representative place, next to one of the main crossings in the site. Now there is only an empty grey wall with a door in the bottom. So, it is proposed to put two planters on both sides of the door. with some green climbing plants, and if it is needed to fully cover the wall, to add some plants in pocket pots attached above the entrance (fig. 10.7. and 10.8.).

Figure 10.7. and 10.8. Proposal for a wall. Before and after. Own elaboration

Some improvements could be made when it comes to permeable surfaces, like in many American cities (fig. 10.9.). All the parking places in the settlements are covered with impervious materials. That is why there could be changed into biologically active surfaces with a grid material. There is also one place in front of a building where the wall is proposed, and where it is possible to reduce the area of impervious surface and implement some low greenery.

Another possibility in the architectural sphere is making some shelters of the bus stops green, like it was done in Białystok (fig. 10.10.). As most of the shelters are located along Wielkopolska Street, the green bus stops are proposed on both sides for ‘Lidzka’ and ‘Racławicka’ bus stops.

Figure 10.9. Permeable alleys in Detroit, the USA. Source: https://daily.jstor.org/to-battle-floods-cities-revive-their-long-forgotten-alleyways/

Figure 10.10. Green bus stop. Source: FPP Eviro, Białystok City Office, https://www.lifetreecheck.eu/en/Databaze/2019/Green-Bus-Stops

Figure 10.11. Project of implementing green solutions in site ‘B’. Own elaboration

In site ‘B’, almost all the buildings in this site have no flat roofs, installing green roofs there is not possible. Also, the parking places are permeable, so it is hard to increase the biologically active surfaces. However, there are possible to implement other solutions (fig. 10.11.).

The terraced houses have their extreme walls windowless, so they are perfect to install on them green walls. As most of the buildings are north-west and south-east oriented, the vegetation is proposed on the south-east walls, together at thirteen buildings. The most representative ones are located on five walls along Kameralna Street. Additional 3 walls are designed on three multi-family houses situated on the other side of the street.

10.3. Water playground

The idea of more nature in cities also evinces in playgrounds. In last years more popular become natural or wild playgrounds instead of the artificial ones. They help children to improve their creativity and are environmentally-friendly.

That is why there is a proposed playground near Racławicka Street. There is currently a complex of playgrounds there, so the new one would complete the system. The site is perfect, because there are small hills and slopes and, although the watercourse goes underground, water gathers on the ground after rainfalls. There would be used only natural materials, wood and stones.

The inspiration for this playground can be a solution from Biberland in Hamburg (fig. 10.12.). It was planned as the retention basin Haferacker was not effective enough, even when it was extended. Also, an old playground needed renovation and the residents were in need of a multigenerational recreation area. After releasing the playground, the following flood was a test, which the object passed.

Figure 10.12. Water playground in Hamburg. Source: https://www.hamburg.de/spielplaetze/8719162/regenspielplatz/

Figure 10.13. Rain garden in Stogi, Gdańsk. Own photo

In the case of Racławicka Street, there could be made a drain to Przemysłowy Stream, nevertheless, the water should be transported there were slowly so that the watercourse would

be unburdened. Most of the runoff should be infiltrated. As in the case study, there could appear some educational boards with information about hydrologic cycle.

10.4. Park with a rain garden

On the empty lot along Strzelców Street, according to the local plan, there are plans to realise local public services. The most probable is that there will appear a kindergarten and a pitch. However, the lot is quite big, so the areas around the planned investments can be transformed into a small park with a rain garden (fig. 10.14. and 10.15.). It would be another rain garden in Tricity (fig. 10.13.).

The role of this area would be to gather water from surrounding settlements and preserve it from going down to Racławicka Street. The basin is planned to be in the east part of the plot, as not directly on the flat top of a hill, constituting the west part, in order to collect some runoff coming from that direction. The park will also be a part of a connection between the proposed tree lane along Strzelców Street and greenery by Racławicka Street.

Figure 10.14. and 10.15. Proposal to a new park. Before and after. Own elaboration

10.5. Pocket parks

On the crossing of Witolda and Olgierda Street there is a place that needs only a small improvement to become a pocket park (fig. 10.17. and 10.18.). In a small triangle lot, covered with small stones, there grow some flowering plants. At the moment, there are several sumach bushes and rudbeckia flowers growing around, and in the neighbouring garden there is an apple tree with some branches over the area. It will join the system of existing pocket parks in Gdynia (fig. 10.16.).

Figure 10.16. Pocket park in Pogórze, Gdynia. Source: https://www.gdynia.pl/gdynia-buduje,8153/kosmiczna-kieszonka,558759

New project establishes adding much more flowers and herbs to the pocket park. The surface should also be diversified, so there will be not only gravel, but also some clumps of grass and flowerbeds with perennial plants and bulb plants in order to make the space attractive in different seasons. However, there will be forbidden to use impervious surfaces. There should also appear three benches along the fence. The square is situated just right under a street lamp, so there is no additional lighting needed.

Figure 10.17. and 10.18. Proposal to a new pocket park. Before and after. Own elaboration

10.6. New tree lanes and green belts

Wielkopolska Street has a big potential in being planted with tree lanes on both sides, and partially in the middle of the road (fig. 10.19. and 10.20.). The lanes are planned not only there, but also along Kameralna and Spokojna Streets.

The most important solution must be done in order to improve the connectivity of the area. There are three main complexes of greenery seen on the site that are not joined with one another. In the north there is a relatively small clump of trees located on the hill. In the south west, there is a belt of greenery, that is the south reaches the forest, and finally, in the east there is a park, that smoothly changes into a complex of woods. As the structure between them is quite densely built-up, the solution may be implementing tree lanes or tree alleys along the streets. Also, the spaces that are not built-up yet, but are planned to, should be designed to make enough space for such a connection.

Such a place is situated in the east, where Bernadowo Park is going to be expanded by two multi-family houses and a service building. At this moment, there is just a big gravel square. So, starting in the Family Park, the new lane should go through the complex of future buildings and join a small clump of bushes along Kameralna Street. Then the trees will be planted on the south part of this street, as there is more space than on the north side. Finally, the lane will join the green belt on the west.

A quite short lane is planned to make a connection with the clump of trees on a hill. It will appear between edge buildings of Merano Park settlement and the old development located by Spokojna Street. As the settlement is fenced, it is suggested to move the fence and enable the access to the green area for pedestrians by creating a green path that should be at least two metres wide. What is important, there should be made another connection in the north of the clump, to not create a ;blind alley'. The connection in the north will flow between housing buildings and service buildings and go to the other side of Parkowa Street to greenery along Wielkopolska Street.

Figure 10.19. and 10.20. Proposal to a green belt along Wielkopolska Street. Before and after. Own elaboration

10.7. Conclusions

Finally, used solutions could be summarised. Exact location of each idea is presented on the figure 10.21. So, in the scale of the district, there is proposed a net of connections and implementing tree lanes. Other solutions are dedicated to a smaller scale. Among architectural solutions, there are green roofs, green walls and green bus stops. To water-based examples include a water playground and a rain garden. A new pocket park and permeable surface can be qualified to the last category of solutions. This shows that even in a relatively small area with quite a lot of greenery, still several elements of blue and green infrastructure can be easily implemented.

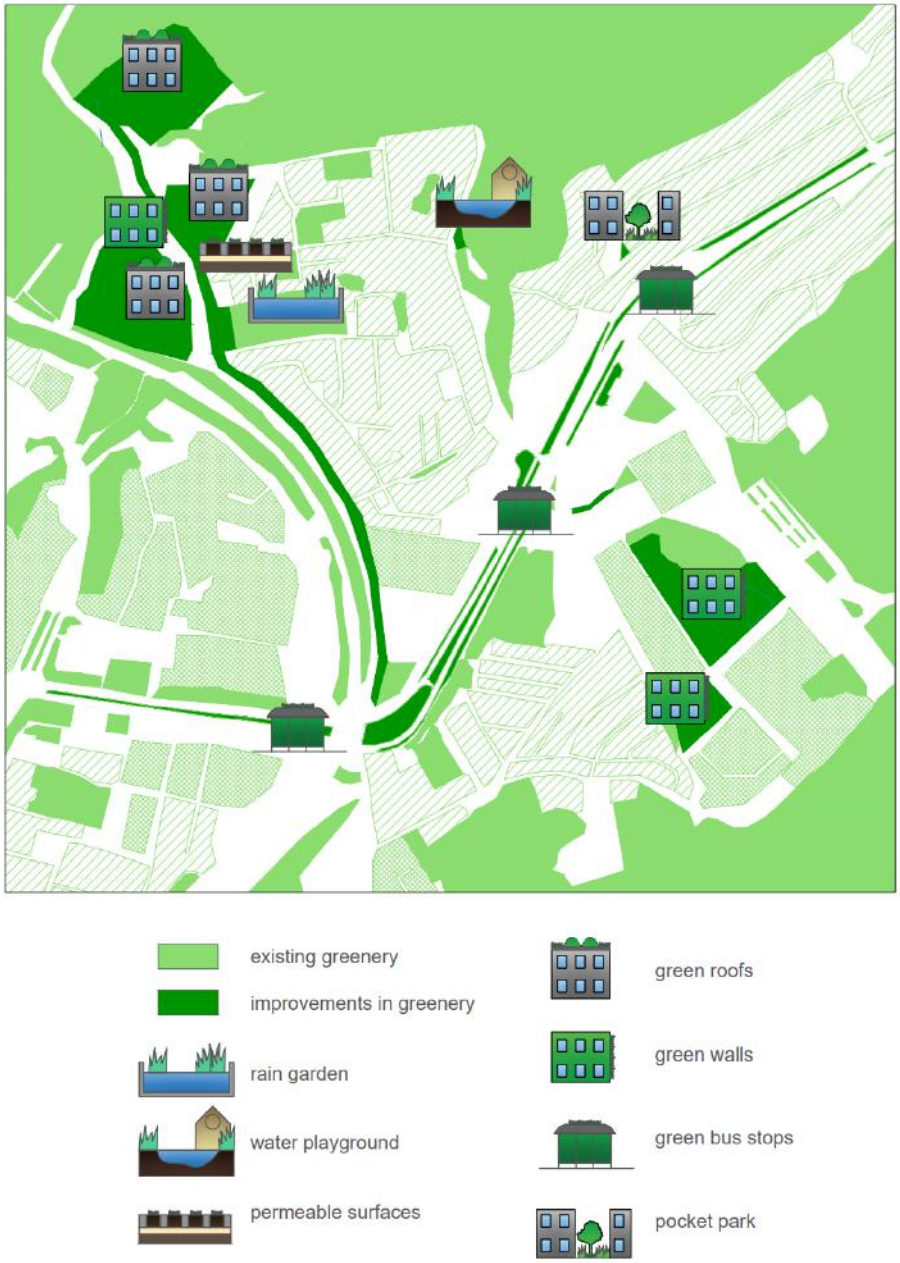

Figure 10.21. Scheme of green solutions of area. Own elaboration

11. SUMMARY

Effects of climate change are a real problem that has a huge impact not only on functioning cities, but also on quality of life. Among them, there is a phenomenon of urban heat island, which, by increase in temperature, influences human health in a negative way. Conducted examination showed that the problem appears, even on a local scale. In such urban areas, which are still developing and putting more and more pressure on the environment, it is important to mitigate these effects.

In the thesis there was made a focus on one of the elements of a resilient city - blue and green infrastructure. It was described how complex it is, there was a theoretical overview and how it may be used in a practical way.

The study shows that many cities realised these problems and implemented a wide range of solutions in different scales, starting from venting green corridors in Stuttgart and superblock concept in Barcelona, to rain gardens and changing the surface to more permeable in Tricity. Whole Metropolitan Area of Tricity is a very valuable environmentally site, as it is located by the Gulf of Gdańsk and near many forested hills, protected by Tricity Landscape Park and many natural reserves, where it could be found river valleys and coast as well. However, this location puts a huge pressure on the environment, as the city has to develop and humans often use the natural and semi-natural sites, because they are very attractive for them.

Mały Kack is definitely a green district, as many parts of it are covered with forest and other types of greenery. The west part of the district is currently one of the most developing areas in Gdynia. The examination of measuring temperature showed that even in the scale of a district appears the phenomenon of urban heat island, and on sunny days the amplitudes in temperature reaches over 3,5 degrees. That is why it is an important goal to mitigate it with particular solutions.

The project establishes implementation some green improvements to buildings, especially the multi-family ones, gathered in bigger complexes. There are planned 25 green roofs and over a dozen green walls. Also, some smaller interventions, like a rain garden, a water playground and a pocket park, would make the district even more green and sustainable. Finally, the greenery must be planned as a system, so each solution and green area would be connected by a tree lane or a green belt.

The thesis points that there is never enough greenery in cities and there are many possibilities to increase the amount of it, and help to mitigate the negative effects of climate change. Even the smallest intervention, the simplest idea, is a next step to make the space where humans live more resilient to what the future will bring.

LITERATURE

1. *7 sposobów, jak poprawić bioróżnorodność w mieście* [online]. Green Projects. 3.06.2021, https://www.green-projects.pl/7-sposobow-jak-poprawic-bioroznorodnosc-w-miescie/ [available: 29.09.2022]
2. Bilska A.: *Proces budowy miasta odpornego na przykładzie Rotterdamu* [online]. In: Rozwój Regionalny i Polityka Regionalna 34, 2016, s. 59-78. Instytut Geografii Społeczno-Ekonomicznej i Gospodarki Przestrzennej UAM, https://core.ac.uk/download /pdf/144757.pdf544 [available: 29.09.2022]
3. *Bioróżnorodność i jej znaczenie* [online]. Zintegrowana Platforma Edukacyjna, https://zpe.gov.pl/a/bioroznorodnosc-i-jej-znaczenie/D1FBuSNZB [available: 29.09.2022]
4. *Błękitno-zielona infrastruktura dla łagodzenia zmian klimatu w miastach.* Katalog techniczny [online]. Berlin - Kraków: Ecologic Institute & Fundacja Sendzimira, 2019, https://www.ecologic.eu/sites/default/files/publication/2020/3205-blekitno-zielona-infrastruktura-dla-lagodzenia-zmian-klimatu-w-miastach-katalog-techniczny.pdf [available: 29.09.2022]
5. Budżet Obywatelski Miasta Gdyni. Poprzednie edycje [online]. Strona Internetowa Miasta Gdyni, https://bo.gdynia.pl/poprzednie-edycje-2/ [available: 28.11.2022]
6. *Chicago Green Alley Project*: Permeable Pavers [online]. Flickr, https://www.flickr.com/photos/centerforneighborhoodtechnology/14702865060 [available: 28.11.2022]
7. *Climate Change 2021: The Physical Science Basis* [online]. Intergovernmental Panel on Climate Change, https://www.ipcc.ch/report/ar6/wg1/ [available: 29.09.2022]
8. Czarnecki W.: *Planowanie miast i osiedli. Tom III. Krajobraz i tereny zielone.* Warszawa - Poznań: Państwowe Wydawnictwo Naukowe, 1968
9. *Dlaczego nasze miasta wysychają? "Realizujemy plany powstałe kilkanaście lat temu"* [online]. Tokfm.pl, 27.07.2021, https://www.tokfm.pl/Tokfm/7,103085,27370744,przez-zaniedbania-systemowo-pozbywamy-sie-wody-ekspert-o.html [available: 28.11.2022]
10. *Don't miss Barcelona* [online]. Spain's official tourism portal, https://www.spain.info/gcc/en/images/dont-miss-barcelona/ [available: 28.11.2022]
11. *Drzewa z węzła Karwiny w bezpiecznej przystani* [online]. Serwis internetowy Miasta Gdynia. 19.08.2020, https://www.gdynia.pl/dla-mediow/komunikaty,4100/drzewa-z-wezla-karwiny-w-bezpiecznej-przystani,551285 [available: 29.09.2022]
12. Fijak M.: *Najsłynniejszy polski ogród na dachu kończy 20 lat. Wyprzedził modę o dekady* [online]. SmogLab, 14.05.2022, https://smoglab.pl/ogrody-buw-20-lat/ [available: 28.11.2022]
13. Freehill-Maye L.: *To Battle Floods, Cities Revive Their Long-Forgotten Alleyways* [online]. JSTOR Daily, 11.09.2018, https://daily.jstor.org/to-battle-floods-cities-revive-their-long-forgotten-alleyways/ [available: 28.11.2022]

14. Gajos D.: *Jezioro Kackie - bogactwo przyrody w środku miasta* [online]. Muzeum Miasta Gdyni, https://muzeumgdynia.pl/2022/05/jezioro-kackie-bogactwo-przyrody-w-srodku-miasta/ [available: 29.09.2022]
15. *Gdyńskie ogrody deszczowe* [online]. Klimada 2.0. Baza wiedzy o zmianach klimatu, https://klimada2.ios.gov.pl/ogrod-deszczowy/gdynskie-ogrody-deszczowe/ [available: 29.09.2022]
16. Główny Urząd Statystyczny [online], https://stat.gov.pl/ [available: 29.09.2022]
17. *Green Bus Stops* [online]. Life Tree Check, https://www.lifetreecheck.eu/en/Databaze/2019/Green-Bus-Stops [available: 28.11.2022]
18. Haber Z., Urbański P.: *Kształtowanie terenów zieleni z elementami ekologii.* Poznań: Wydawnictwo Akademii Rolniczej im. Augusta Cieszkowskiego w Poznaniu, 2005
19. *Historia zielonych ścian - kto wpadł na pomysł ogrodów wertykalnych?* [online] 4Nature System, https://4naturesystem.com/pl/blog/bid-106-historia-zielonych-scian-pomysl-ogrodow-wertykalnych [available: 29.09.2022]
20. Hołdys A.: *Zabójcza susza: jakie mogą być jej konsekwencje?* [online] Polityka, 18.08.2015, https://www.polityka.pl/tygodnikpolityka/nauka/1629907,1,zabojcza-susza-jakie-moga-byc-jej-konsekwencje.read [available: 28.11.2022]
21. Hukało P.: *Wielka ulewa w Gdańsku w 2016 r. Trzy lata temu deszcz zatopił wiele ulic miasta* [online]. Dziennik Bałtycki. 14.07.2019, https://dziennikbaltycki.pl/wielka-ulewa-w-gdansku-w-2016-r-trzy-lata-temu-deszcz-zatopil-wiele-ulic-miasta-zdjecia-wideo/ar/c1-12255725 [available: 29.09.2022]
22. John H., Marrs C., Neubert M. [red., 2019]. *Podręcznik zielonej infrastruktury – Tło koncepcyjne i teoretyczne, terminy i definicje, wersja skrócona w języku polskim* [online]. Project Interreg Central Europe MaGIC Landscapes. Produkt O.T1.1, Drezno. Z udziałem: Z. Jała, D. Wojnarowicz, https://www.interreg-central.eu/Content.Node/MaGICLandscapes-Podrecznik-Zieloney-Infrastruktury.pdf [available: 29.09.2022]
23. Jürgens I.: *Grüne Fassaden für ein besseres Stadtklima* [online]. Berliner Morgenpost, https://www.morgenpost.de/nachhaltigkeit/article233689249/Gruene-Fassaden-fuer-ein-besseres-Stadtklima.html [available: 28.11.2022]
24. Kosmala M.: *Tereny zieleni wobec zmian klimatu.* Toruń: Polskie Zrzeszenie Inżynierów i Techników Sanitarnych Oddział Toruń, 2016
25. *„Kosmiczna kieszonka". Centrum wszechświata na Pogórzu* [online]. Serwis internetowy Miasta Gdynial, 2.08.2021, https://www.gdynia.pl/gdynia-buduje,8153/kosmiczna-kieszonka,558759 [available: 28.11.2022]
26. Köllinger C.: *Study suggests significant benefits from Barcelona's superblocks* [online] Eltis. The Urban Mobility Observatory, https://www.eltis.org/in-brief/news/study-suggests-significant-benefits-barcelonas-superblocks [available: 28.11.2022]

27. *Miejska Wyspa Ciepła* [online]. Klimada 2.0. Baza wiedzy o zmianach klimatu. 7.08.2020, https://klimada2.ios.gov.pl/miejskie-wyspy-ciepla/ [available: 29.09.2022]
28. *Miejska wyspa ciepła w Warszawie* [online]. Warszawa: Wydawnictwo Akademickie SEDNO, 2014, http://rcin.org.pl/Content/56055/WA51_74963_r2014_Miejska-wyspa-ciepla.pdf [available: 29.09.2022]
29. *Neugraben-Fischbek Regenwasser-Spielplatz – "Biberland"* [online]. Hamburg.de, https://www.hamburg.de/spielplaetze/8719162/regenspielplatz/ [available: 28.11.2022]
30. *Nietoperze* [online]. Encyklopedia Gdańska. 24.09.2022, https://gdansk.gedanopedia.pl/gdansk/?title=NIETOPERZE [available: 29.09.2022]
31. *Ogrody na ścianie* [online]. Magazyn Ciepła Systemowego, 4.01.2021, https://magazyncieplasystemowego.pl/miasta-przyszlosci/ogrody-na-scianie/ [available: 28.11.2022]
32. Orzeszek-Gajewska B.: *Kształtowanie terenów zieleni w miastach.* Warszawa: Państwowe Wydawnictwo Naukowe, 1982
33. *Paley Park* [online]. Project for Public Spaces, https://www.pps.org/places/paley-park [available: 28.11.2022]
34. *PLH220105 Klify i Rafy Kamienne Orłowa* [online]. Regionalna Dyrekcja Ochrony Środowiska w Gdańsku. 30.12.2021, https://www.gov.pl/web/rdos-gdansk/plh220105-klify-i-rafy-kamienne-orlowa [available: 29.09.2022]
35. *Potrzeba globalnego porozumienia dla przyrody i ludzi* [online]. Green Projects. 6.11.2018 https://www.green-projects.pl/globalne-porozumienie-dla-przyrody-raport-wwf/ [available: 29.09.2022]
36. Ptaszycka A.: *Przestrzenie zielone w miastach.* Warszawa: Ludowa Spółdzielnia Wydawnicza, 1950
37. *Rezerwat przyrody Ptasi Raj w Górkach Wschodnich* [online]. Wyspa Sobieszewska Wyspa.pl. 24.04.2018, https://www.wyspa.pl/wyspa-sobieszewska/rezerwat-przyrody-ptasi-raj-w-gorkach-wschodnich [available: 29.09.2022]
38. *Rezerwaty przyrody* [online]. Pomorski Zespół Parków Krajobrazowych. Trójmiejski Park Krajobrazowy, https://tpkgdansk.pl/o-parku-7/formy-ochrony-przyrody-3/rezerwaty-przyrody-2/ [available: 29.09.2022]
39. *Schriftenreihe des Amtes für Umweltschutz* - Heft 3/2010 [online]. Landeshauptstadt Stuttgart, https://climate-adapt.eea.europa.eu/en/metadata/case-studies/stuttgart-combating-the-heat-island-effect-and-poor-air-quality-with-green-ventilation-corridors/afu-heft-3-2010-web.pdf [available: 28.11.2022]
40. *Sedum Roof Staffordshire* [online]. Specifer Review, https://specifierreview.com/2018/07/24/sedum-roof/ [available: 28.11.2022]
41. Strzałkowski M.: *Nawet milion gatunków zagrożonych wyginięciem* [online]. EURACTIV.pl. 9.10.2019, https://www.euractiv.pl/section/energia-i-

srodowisko/news/nawet-milion-gatunkow-zagrozony-wyginieciem/ [available: 29.09.2022]

42. *Superblocks. A sustainable strategy for regenerating the city* [online]. Architecture walks and tours in Barcelona, 24.05.2016, https://barcelonarchitecturewalks.com/superblocks/ [available: 28.11.2022]
43. *Środowisko przyrodnicze. Rezerwaty przyrody* [online]. Serwis internetowy Miasta Gdynia. 28.08.2006, https://www.gdynia.pl/mieszkaniec/srodowisko-przyrodnicze,3673/rezerwaty-przyrody,365371 [available: 29.09.2022]
44. *To było piekło. Cztery lata po nawałnicy w Borach Tucholskich* [online]. TVP3 Bydgoszcz https://bydgoszcz.tvp.pl/55314908/cztery-lata-po-nawalnicy-w-borach-tucholskich [available: 28.11.2022]
45. *Urbanization* [online]. Our World in Data. November 2019, https://ourworldindata.org/urbanization [available: 29.09.2022]
46. Zielonko-Jung K.: *Miasto i wiatr* [online]. Architektura&Biznes, 9.05.2019, https://www.architekturaibiznes.pl/miasto-i-wiatr,1738.html [available: 28.11.2022]

Maps

47. *Formy ochrony przyrody* [online]. Geoserwis mapy. Generalna Dyrekcja Ochrony Środowiska, https://geoserwis.gdos.gov.pl/mapy/ [available: 29.09.2022]
48. *Mapy Google* [online]. Google, https://www.google.com/maps/@54.4737312,18.5139421,14.29z?hl=pl-PL [available: 29.09.2022].
49. OpenStreetMap [online]. © autorzy OpenStreetMap, https://www.openstreetmap.org/#map=15/54.4712/18.5082 [available: 29.09.2022]:
50. *Retromapy Gdynia* [online]. Retromapy, https://gdynia.retromapy.pl/ [available: 29.09.2022]
51. *Skany map topograficznych* [online]. Geoportal, https://mapy.geoportal.gov.pl/imap/Imgp_2.html?gpmap=gp0 [available: 29.09.2022]

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APPENDIXES

ARTICLE

The role of green infrastructure in mitigation of the climate change effects. Examination of an urban heat island in Mały Kack, Gdynia

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Master studies of Gdańsk University of Technology

Article Info:

Keywords:

green infrastructure

urban heat island

resilient city

climate change effects

Abstract

Higher temperature, urban flooding, extreme weather conditions are the effects of climate change that appear in the structure of the cities. There are many actions undertaken to reduce this problem and implementing green and blue infrastructure is one of them. Although Gdynia seems to be a very green city, as about 46% of its surface is covered by forests, there are some places in the urban structure, where increasing the amount of greenery may be effective. This research helps to identify areas of potential problems, by conducting own temperature measurements. The main area of interest was focused on Mały Kack, a south located district of Gdynia, which urbanised areas separate two parts of Tricity Landscape Park. As a result, some enhancements were proposed in places where the connections of green infrastructure are interrupted and several green interventions were designed in the areas that suffer the most from urban heat island.

Streszczenie

Wysoka temperatura, miejskie powodzie, ekstremalne warunki pogodowe są skutkami zmian klimatu, które są odczuwalne w miastach. Wiele podejmuje się, aby zminimalizować ten problem, i wprowadzanie zielono-niebieskiej infrastruktury jest jednym z takich sposobów. Mimo, iż Gdynia zdaje się być bardzo zielonym miastem, jako że około 46% powierzchni miasta pokryte jest lasami, są pewne miejsca w strukturze urbanistycznej, gdzie wzrost obszarów zielonych wpłynąłby pozytywnie na otoczenie. To badanie pomaga zidentyfikować możliwe problemy, poprzez własne pomiary temperatury. Głównym obszarem badań była dzielnica Mały Kack w Gdyni, położona na południu miasta, i której tereny zurbanizowane oddzielają dwie części Trójmiejskiego Parku Krajobrazowego. Jako rezultat, zaproponowano kilka ulepszeń w miejscach, gdzie połączenia w strukturze zielonej infrastruktury są przerwane. Zaprojektowano też kilka rozwiązań w miejscach najbardziej narażonych na skutki miejskiej wyspy ciepła.

Introduction

The effects of climate change are a crucial problem nowadays and they are visible in the structure of cities. Among them there is for example urban flooding and an urban heat island, which has an impact on the increase of temperature. An answer to this problem could be a concept of a resilient city. One of its parts are solutions in green infrastructure, because looking at greenery in cities as a system, helps to, among others, accumulate more water and enrich biodiversity. In the thesis there was analysed the situation in the city of Gdynia and there was conducted an examination of measuring temperature in the chosen part of the city.

Methods

To see the urban heat island in the local scale, there were taken own measurements of temperature in several parts of the area designated in the district scale. There were five points chosen with different conditions. The temperature was measured for three days, three times each day - in the morning, in the afternoon and in the evening.

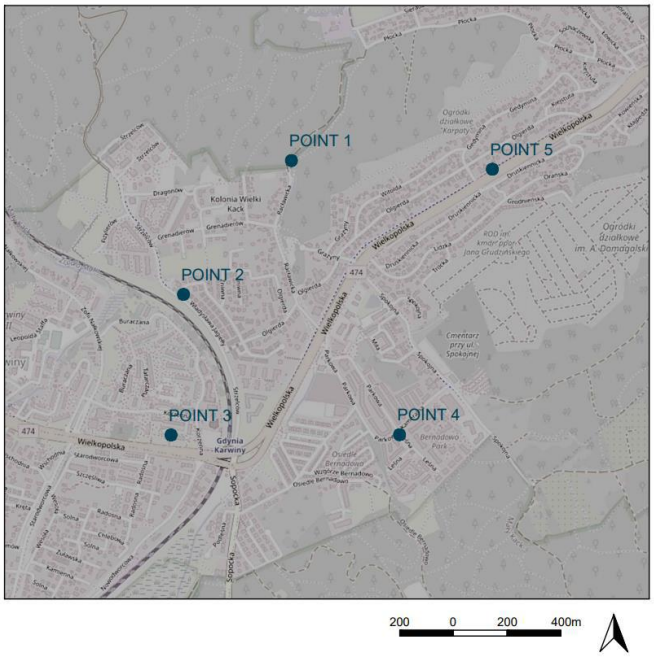

Figure 1.1.. Map with the location of chosen points. Own elaboration.

Also the was measured four kinds of temperature - air temperature in the sunlight, air temperature in the shadow, ground temperature in the sunlight and ground temperature in the shadow. As the most reliable results are reached by measuring air temperature in the shadow, these measurements describe weather conditions, and could be easily compared to the ones presented in the local weather forecast. However, humans also perceive other types of temperature, that is why they were also taken into account. The location of the points is presented on the figure 1.1.

The first point is situated at the edge of the forest, on a slope of Przemysłowy Stream, a small watercourse which is a tributary to Kacza River. The temperature was measured at the altitude of about 70 metres above sea level, in the shadowed grass in the closest vicinity of the stream, as well as in the heat forest cover on the east-exposed slope.

Figure 9.7. Point 1 - east-exposed slope in the sunlight. Own photo.

Figure 1.2. Point 1 - Przemysłowy Stream. Own photo.

The second point is located only about 600 metres in the straight line from the first point, but nearly 50 metres higher - at the altitude of 116,5 metres above sea level. This place is a crossing in a single-family housing neighbourhood next to a train line. Until recently there was a tree lane, but unfortunately it was cutted down due to rebuilding the street. The temperature on the surface of the soil and the asphalt was checked.

Figure 1.3. Point 2 - street without tall greenery around. Own photo

Figure 1.4. Point 3 - an interior of an urban block with a playground and some greenery. Own photo.

The next point is the only point located in Karwiny district. It was chosen, as there are multi-family houses from the 80s,and there are no such buildings in Mały Kack. The selected area was a green interior of an urban block building quarter with a playground on the altitude of 119,5 metres

above the sea level and there was measured the temperature of grass under bushes and of pavement brick.

A street crossing in Bernadowo Hill was chosen as the fourth point. This crossing is surrounded by relatively new multi-family houses and it is situated at the altitude of 103 metres. Similar to the previous point, the temperature of ground under a tree and of pavement was checked.

The last point is located on Wielkopolska Street, next to the 'Olgierda' bus stop, the one in the direction of Karwiny. The street is one of the main streets of the city and the core of the functioning of the south districts of the city. The altitude of this point equals 75,5 metres above sea level and the thermometers were put on the surface of pavement brick and grass under a bush.

Figure 1.5. Point 4 - a crossing in a new settlement with not much greenery. Own photo.

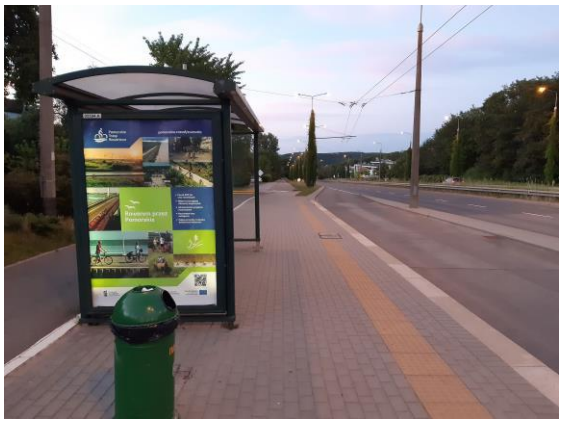

Figure 1.6. Point 5 - the vicinity of the bus stop 'Olgierda'. Own photo.

Before presenting detailed results of temperature measurements, there should also be described general weather conditions during the three days of research. Although it was conducted in July, the temperatures were not scorching these days. The temperature of the air in the shadow was not higher than 27 C degrees and generally was fluctuating between 16 and 21 degrees.

Important factors that influenced the temperature were the percentage of cloudiness of the sky and the humidity, assessed by the presence of rain, and how they were changing during the days. The first morning was quite sunny, however, the later it became, the more clouds came into the sky, with almost no sun in the afternoon. The second day started similarly, however at noon, there occurred a heavy rain, and then during the afternoon research it also rained twice lightly. The beginning of the third day was like the previous two days, so it could be said that all three mornings were sunny. However, in the afternoon it was also raining and the sky was fully clouded.

What should be also noticed, the hours of measuring temperature in the evening took place after sunset, except the second point, which is west-exposed, and last rays of sun reached the ground during the research. In other cases, when the temperature in sunlight is presented, it was actually measured at the place that was exposed to the sun during the day.

Results

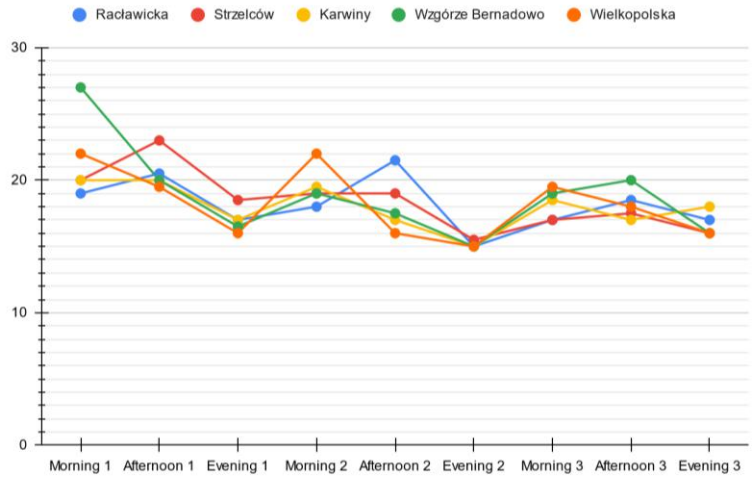

Figure 1.7. Temperature of air in the shadow. Own elaboration

Now, the results between different points will be compared and the temperature of air in the shadow will be taken into account firstly. The highest temperature was measured on the first morning in Wzgórze Bernadowo with the value of 27 degrees and the lowest - in the second evening with the same value of only 15 degrees in all points except Strzelców. Interestingly, the highest temperature in the second afternoon was in Racławicka, the most natural point, and in more urbanised ones it was lower. It indicates that the rain, which appeared that afternoon, decreased the temperature in the more build-up areas.

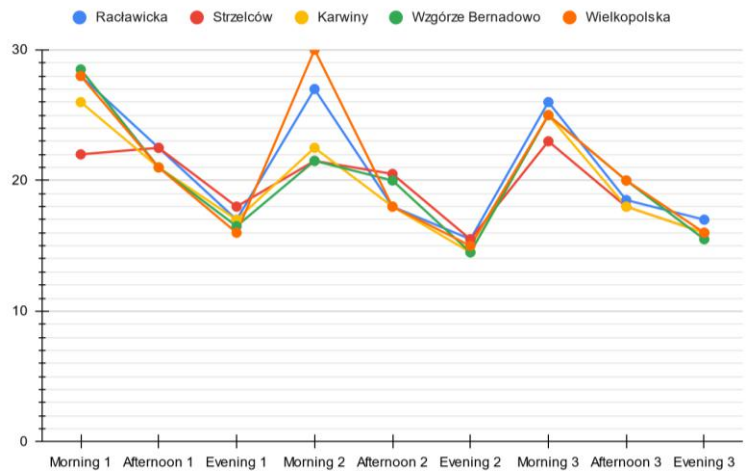

Figure 1.8. Temperature of air in the sunlight. Own elaboration

When it comes to the results of measurements of air in the sunlight, the amplitudes become bigger. The highest value equals 30 degrees was noted in Wielkopolska in the second morning and

the lowest - only 14,5 degrees in Wzgórze Bernadowo in the second evening. The largest amplitudes took place in the first and second morning, according to the influence of the sun.

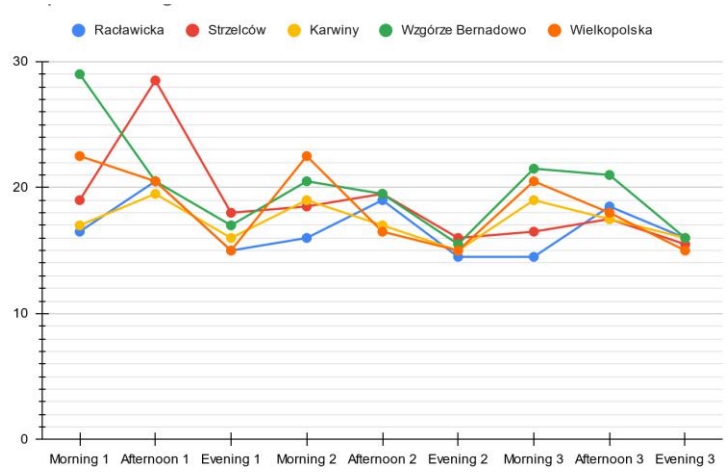

Figure 1.9. Temperature of ground in the shadow. Own elaboration

Very interesting results came when the thermometers were put on ground. The material of each ground was different in different places, but it was chosen the most dominating one. During the research of the temperature of the ground in the shadow, there were chosen the places where the shadow was almost all over the day, like under the bushes etc. However, it was impossible in point 2, as there is not such a place - in any specific place the sunlight came for at least several hours, that is why the results might be disrupted.

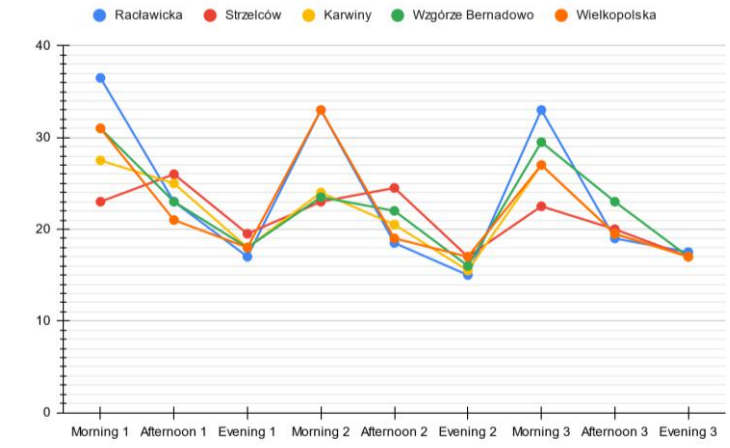

Figure 1.10. Temperature of ground in the sunlight. Own elaboration

Finally, the temperature of the ground exposed to the sunlight was measured. Surprisingly, the highest temperature was reached every morning in point 1. The forest cover located on the east slope preheated during the mornings even to 36,5 degrees. On other parts of days, the temperature in other points was higher, but as it was described above, there were not many sunny days, so the value

rarely passed the level of 30 degrees. But what should be also noted, the amplitudes of the temperature of ground in sunlight are bigger than the ones in shadow.

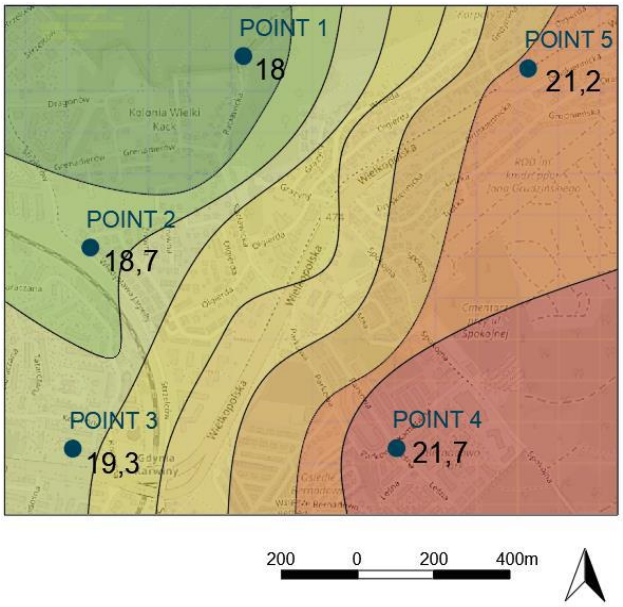

Figure 1.11. Map with the average temperatures gathered from all three mornings of examination. Own elaboration

The results of measuring temperature in the mornings are present in the figure… The amplitude between different parts of the site are very high and reach 3,7 degrees. The coldest part is the north-west corner, where the forest valley was examined, so it is not surprising - the big complex of greenery cools down the temperature. The hottest was crossing in Bernadowo Hill, surrounded by housing estates.

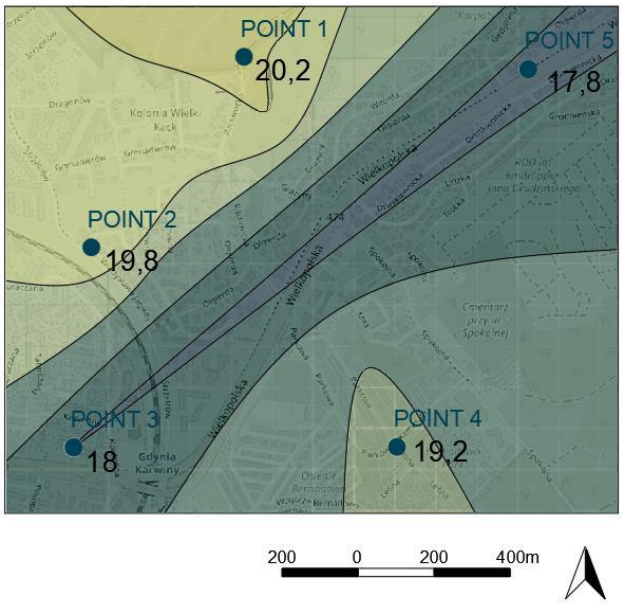

Figure 1.12. Map with the average temperatures gathered from all three afternoons of examination. Own elaboration

The average temperature of three days in the afternoon was cooler than in the mornings. It reached maximum 20,2 degrees, and what definitely should be noted, it was reported in the forest valley. There could be a conclusion that the forest gathered the heat during the sunny mornings, and kept it during the cloudy afternoons. Also in Bernadowo Hill the temperature was quite high. The lowest results were in Olgierda bus stop and in Karwiny, which yielded in a cold corridor along Wielkopolska Street on the map.

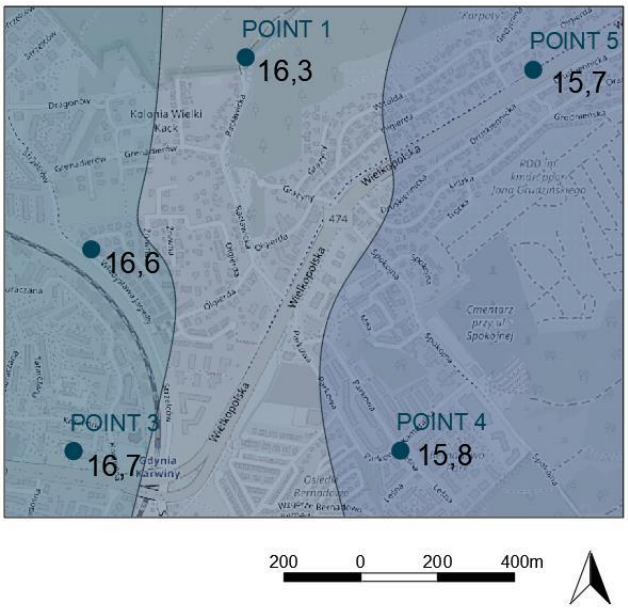

Figure 1.13. Map with the average temperatures gathered from all three evenings of examination. Own elaboration

Finally, the amplitudes in the evening were the lowest and reached only one degree. The hottest were the west part, which is the longest exposed to the sunlight.

Conclusions

The conducted research showed that the problems with local urban heat island may occur in the site and, what was quite surprising, sometimes the differences in temperature between particular places are high. The phenomenon appears not only in the scale of the whole city and is not only connected with dense urban structures of city centres, but also appears in more suburban or located directly to big complexes of forest areas. Types of buildings, distance to green area, height above sea level or sunlight exposure change the conditions significantly.

As a result, humans perceive these conditions differently and may be vulnerable to the changes that appear. Even if there seems to be a lot of greenery, there is still a reason to implement more blue and green infrastructure here, which would help to mitigate the effects of climate change.

This examination helped to launch the next step of work. It is the premise to green solutions, that are represented by 25 green roofs on multi-family houses, over a dozen green walls, several green bus stops, a pocket park and a rain garden. There was also designed a net of green connections, formed by tree lanes, tree alleys and green belts.

Literature

1. *Miejska Wyspa Ciepła* [online]. Klimada 2.0. Baza wiedzy o zmianach klimatu. 7.08.2020, https://klimada2.ios.gov.pl/miejskie-wyspy-ciepla/ [available: 29.09.2022]
2. *Miejska wyspa ciepła w Warszawie* [online]. Warszawa: Wydawnictwo Akademickie SEDNO, 2014, http://rcin.org.pl/Content/56055/WA51_74963_r2014_Miejska-wyspa-ciepla.pdf [available: 29.09.2022]