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COMBINATION OF ARCHITECTURAL, ENVIRONMENTAL AND SOCIAL ASPECTS IN URBAN STORMWATER MANAGEMENT. A CASE STUDY OF THE UNIVERSITY CAMPUS

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Abstract

Increasing a city's resilience against climate change is one of the major concerns of today. Sustainable stormwater management, using Green Infrastructure units (GI) integrated with an urban area, has proved to be effective in flooding control and to offer extra benefits encompassing groundwater recharge, stormwater treatment, mitigation of air pollution, and an urban micro-climate. Moreover, GI brings cultural benefits for the urban population. However, the "grey" solutions are still popular and widely accepted. This paper presents three conceptions of the revitalisation of a part of campus of the Gdansk University of Technology with different approaches to stormwater management. The first approach ("blue-grey") is purely based on an architect's vision, and has some negative aspects from the environmental point of view. The second approach ("blue-grey-green") is a modification of the previous one, in an attempt to introduce green elements and to obtain more ecosystem services. The third conception ("blue-green") is fundamentally different, as it relies on GI elements and attempts to respond to the needs reported by the local community of students and university employees accordingly to opinion polls that were conducted. The three solutions are discussed in terms of water sensibility, aesthetics, functionality, usability, and public perception.

***Keywords**: Sustainable stormwater management, Urban stream syndrome, Ecosystem services, Green Infrastructure, Retention, Rain gardens*

Introduction

Water has been vital for the development of the cities, used not only for drinking and food production but also for transportation, the production of goods, for protection against enemies (ditches, moats) as well as for micro-climate mitigation, as in the former Muslim towns at the Iberian Peninsula.

The present concepts of water presence and management in the cities still have their roots in the XIX century, when the role of water in transmitting diseases and the significance of proper hygiene and sanitation were first understood. The technical concepts of centralised water provision and wastewater collection were then developed, and they continue to shape the nowadays urban areas, especially in developed and industrialised countries [1]. Starting from the first infrastructure built in the XIX century, stormwater has been looked at as one of the elements to be included within the engineered systems for water and wastewater transport [2,

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3]. In combined sewerage systems, stormwater is mixed with wastewater, while separate sewers consist of separate systems for wastewater and stormwater transport. Regardless of the system type, this 150 year old approach to stormwater management is no longer feasible in the rapidly expanding cities of today. Firstly, the urban drainage infrastructure is no longer able to transport the huge stormwater volumes, constantly enlarging due to increasing imperviousness of urban areas and climatic changes bringing more intensive rainfalls [4, 5]. The problem of urban flash floods is becoming more and more common and touches cities worldwide [6].

However, urban flooding is not the sole reason for seeking more sustainable and effective ways of urban stormwater management. The list of problems arising from traditional stormwater management is long, not to mention low flows in urban streams and rivers during dry periods, which generates further effects known as "urban stream syndrome" [7]. Other problems include reduced underground outflow and groundwater recharge, as well as poor quality of stormwater transported in the urban drainage systems. At the same time, the introduction of sustainable stormwater management relying on Green Infrastructure (GI) not only helps to overcome the aforementioned problems, but it also brings a set of other positive aspects like micro-climate regulation, increasing a city's resilience towards climate change, cultural and aesthetic values, and generally contributes to arrange cities in a way that makes them more "liveable". The sum of ecosystem services associated with GI facilities for stormwater management is thus definitely greater than the single effect of urban flood control [8-11].

Due to city space limitations and strong competition for urban terrains between various groups of interest, the main task is the wise planning of urban infrastructure corresponding to the needs of local communities, but bearing in mind the fundamental regulatory services, functionality, and future exploitation as well as aesthetic aspects. Developed concepts need to be carefully examined before they are implemented [12, 13].

The aim of this paper is to present and compare three various concepts of stormwater management at part of the campus of the Gdansk University of Technology (GUT). The first approach, further referred to as "blue-grey", was basically the architect's concept corresponding to a broader vision created for the whole university campus. This concept was rather technical and had some negative aspects from the environmental point of view, thus the second approach ("blue-grey-green") modified the previous one in an attempt to introduce green elements and to obtain more ecosystem services. The third conception ("blue-green") presents a fundamentally different approach as it relies on GI elements. At the same time, it tries to respond to the needs reported by the local community of students and university employees accordingly to opinion polls that were conducted.

Organisation of the manuscript is as follows: in Methods, basic information regarding the site, its climate, hydrology and present land management are provided, followed by a description of calculation methods and opinion polls. The section Results provides a detailed description of the three concepts of stormwater management. This section is followed by a Discussion regarding the positive and negative aspects of the three conceptions in the light of social attitude and ecosystem services provided.

Experimental methods

Site description including hydrological and climatic aspects

Characteristics of GUT campus

Gdansk is a city with almost 600,000 inhabitants, located on the southern coast of the Baltic Sea. The campus of the Gdansk University of Technology (GUT) covers an area of 44.8ha and it is located in the eastern part of one of the older districts of the city – Wrzeszcz.

GUT has 9 faculties, and almost 120 buildings including students' dormitories. In the main part, between Fiszera, Traugutta, Do Studzienki and Grunwaldzka streets, 29 buildings are located. The terrain between the buildings is sealed without green terrains inside, though there are some green areas adjacent to the campus. However, the only accessible green terrain is an academic park located near the central and eastern parts of the campus.

Hydrological characteristics of GUT location

Gdansk is located at the edge of the moraine highland of the Kashubian Lake District, with the terrain level rapidly falling from the height of 150m above sea level to 0m above sea level at the sea coast [14]. Morphologically, GUT is located in the valley of one of the fluvioglacial streams – the Królewski Stream (King's Stream) which crosses the campus area in its middle-run. The Królewski Stream takes its origin in the moraine hills and forms a large valley with attitudes ranging from 58 to 5.4m over sea level and slope inclinations above 3%. The Stream is 3.954km long and has a catchment area of 2.996km^{2,} and it outflows to the Strzyża Stream in the southern part of the Wrzeszcz district. In the 1970s, part of the Stream's bed was channelised. Figure 1 presents the location of the Królewski Stream on a map with the watercourses of the Gdansk Water System, as well as the channelised part of the Stream. Channelisation of the Stream caused rapid urbanisation and an increase in the sealed area, especially in the middle and lower part of the catchment area. The high share of sealed areas together with a high hydraulic gradient and terrain slopes in the upper part of the catchment cause a flooding risk in the middle and lower parts. Flow rate monitoring started in 2013 [15], showing high intermittency of flows, ranging from low non-recordable flows in dry periods and increasing sharply after torrential rainfalls.

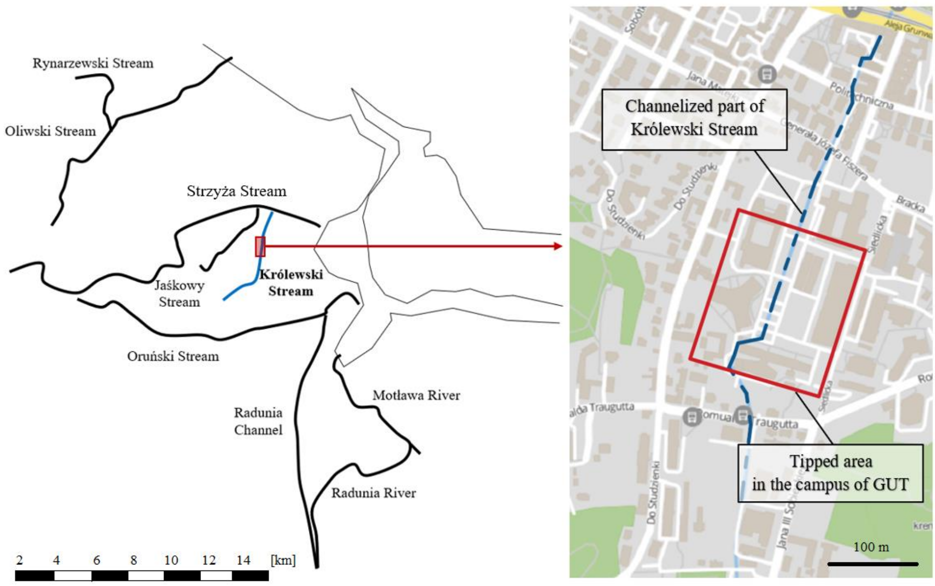

Fig. 1. The location of the Królewski Stream on the map, with watercourses of the Gdansk Water System and the channelised part of the Królewski Stream between Sobieskiego Street and Grunwaldzka Avenue

Water quality of the Królewski Stream

Data on the water quality of the Królewski Stream are scarce, since the Stream is not included in the regular monitoring performed by the city. This is explained by the fact that the prevailing part of the Stream bed is covered, without access to sampling. The short segments in the upper part of the Stream when it flows in an open channel are characterised by very low flow rates unless intensive rainfall occurs. Mikos-Studnicka & Szydłowski [16] report the following ranges of concentrations of the basic water quality indicators for the Królewski Stream: total suspended solids (TSS) 0.002 – 0.002mg/L, BOD_5 1 – 43mg O_2/L, COD 7 – 68mg O_2/L, ammonia nitrogen 0.01 – 0.65mg/L, nitrates 0.52 – 1.32mg/L, total nitrogen (TN) 0.4 – 5.49mg/L, total phosphorus (TP) 0.16 – 0.53mg/L, chlorides 7 – 106mg/L. These broad concentration ranges correspond to a wide range of water quality classes, from the first class (excellent quality) to fourth or even fifth (very poor environmental status). Especially BOD_5 concentrations can be considered as very high. The incidents when water quality deteriorates, similarly as in other streams in the region, are generally associated with rainfall events due to pollutant discharge with the surface runoff [17-19].

Description of the campus area adjacent to the Królewski Stream bed

The research site is a part of the GUT campus adjacent to the bed of the Królewski Stream. The part of the stream flowing through the campus is channelised and flows underground in two parallel pipes, 1200mm diameter each. Both pipes are linked every several tens of metres by concrete revision tanks. The campus area adjacent to the Stream is situated between the buildings of the Faculty of Mechanical Engineering (ME), Faculty of Ocean Engineering and Ship Technology (OEST) and Faculty of Electronics, Telecommunications, and Informatics (ETI) presented in figure 2.

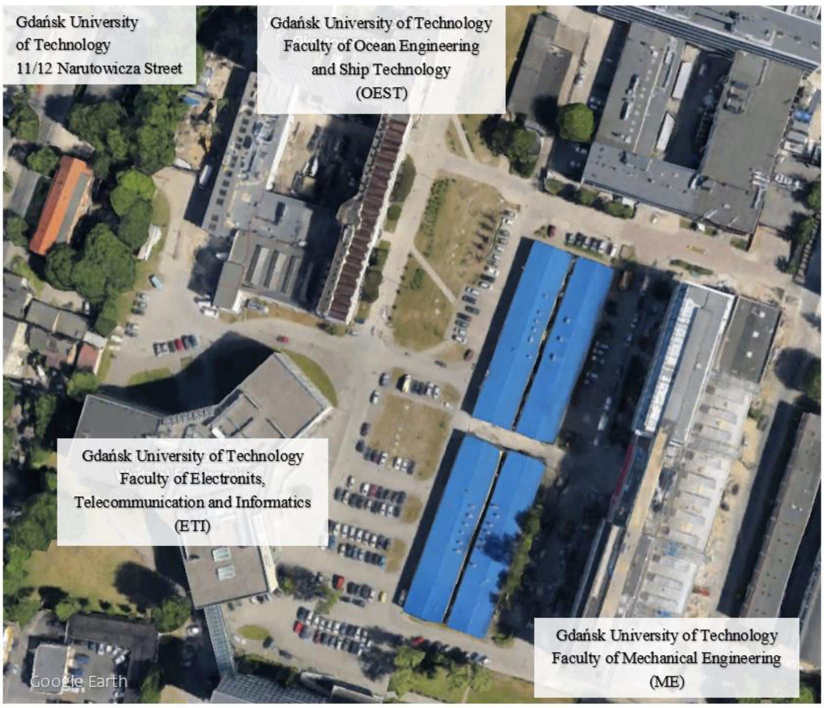

Fig. 2. Location of the part of GUT campus adjacent to the bed of the Królewski Stream (source: Google Earth) [20]

The total area between these buildings covers approx. 1.5ha. The site is rather flat, with terrain attitudes ranging from 10.17 to 11.30m above sea level. At present, part of the terrain is used as parking lots (sealed) and is crossed with several concrete walking passages and asphalt roads. In the central part of the area, there are twin warehouse buildings of lightweight construction. The green areas occupy only a small part of this large area. At the moment, the only above-ground accent that might indicate the presence of the stream flowing underneath is the blue colour of the roofs of the twin warehouse buildings located directly on the stream route

(Fig. 2). Due to the fact that spatial development of this part of the campus is rather random, some revitalisation is planned in the future to make it a fairly functional and representative part of the university area.

Climate characteristics

Gdansk is located in a temporate climate zone with a strong marine influence. High spatial and seasonal variability of the rainfall amount is observed. The average yearly rainfall is equal to 522mm [21], with the maximum in summer months (June – August) equal to 65mm for each month on average [22]. Rainfall observations show high spatial variability among different city districts ranging from 560 mm in the lower part of the city to 650-700 mm in the moraine part [23]. The yearly temperature amplitude is equal to 18.4°C; the coldest month is January (0.5°C) and the hottest – July (20.4°C). The climate change scenarios for central and eastern Europe [4, 24] assume the rise of summer temperatures, an increase of summer drought events, minimisation of winter snow cover and the increase of winter month rainfall amount. On the other hand, an increase of torrential summer rainfalls is predicted. Such rainfall events have already been recorded in recent years (July 2001, July 2016, May 2018, June 2019) causing flooding of the streets and city districts [14, 19, 25].

Stormwater outflow calculations

The stormwater outflow (Q) from the analysed part of GUT campus was calculated using the rational method, according to the formula (1):

$$Q = \cdot\, q \cdot A [L \cdot s^{-1}] \tag{1}$$

where:

Q is a stormwater outflow, $[L \cdot s^{-1}]$

is a runoff coefficient, $[-]$

q is a design rainfall, $[L \cdot s^{-1} \cdot ha^{-1}]$

A is a surface area, $[ha]$

The values of runoff coefficient used in this study are presented in Table 1.

Table 1. The runoff coefficient for different types of surface coverage

Index	Type of surface coverage			
	Roofs	Asphalt and concrete roads and pedestrian walks	Green areas	Permeable parking surface
Runoff coefficient	0.8	0.9	0.1	0.2

The design rainfall was calculated according to empirical formula (2) developed by *Bogdanowicz and Stachy* [26, 23]:

$$q = 166.67 \cdot \frac{hmax}{t} \tag{2}$$

where:

h_{max} is the maximum rainfall amount, $[mm]$ calculated according to the formula (3)

t is the rainfall duration time, $[min]$

$$h_{max} = 1.42 \cdot t^{0.33} + \alpha(R, t) \cdot (-\ln p)^{0.584} \tag{3}$$

where:

p – probability of occurrence of excess rainfalls, $[\%]$

α – parameter dependent on region (in Poland) and duration time t; for marine and Pomerania region $\alpha = 9.472 \cdot \ln(t + 1) - 37.03$

Duration time $t = 10min$ and rainfall probability $p = 50\%$ were assumed for the purpose of the calculations. The average yearly rainfall amount was assumed as $580mm$, following the local guidelines [27, 28]. The design rainfall calculated using these assumptions was equal to $q = 154L \cdot s^{-1} \cdot ha^{-1}$.

Opinion polls

Forty-three students from 3 GUT faculties and 17 university teachers were asked to fill out a short questionnaire consisting of 3 questions and a plan showing the current spatial development of the site. The questions were as follows:

Q1: Which of the present functions should be included in the restoration plan? With the suggested answers: "parking", "connection walks", "none".

Q2: What new benefits do you expect from the planned arrangement of the site? With suggested answers: "green space", "recreation places", "communication", "new parking places". In this question, the participants were allowed to mark two answers.

Q3: What is your attitude to the restoration of the Królewski Stream on this part of the campus? – rating from 1 = "definitely against" to 5 = "extremely positive"

Results and discussion

Description of three site management conception

The three conceptions presented below were developed assuming that the present spatial management of the analysed part of the GUT campus will be revitalised and the twin warehouses with blue roofs (Fig. 2) that have a rather temporary character will be demolished. Moreover, all conceptions assumed some form of restoration of the Królewski Streambed. The first, blue-grey conception was developed by a group of architects. The second one (blue-grey-green) is the development of the previous approach by adding some more "environmental" accents. The third, blue-green conception was based upon the idea of integrating Green Infrastructure elements in the present space, leaving some functions (parking places) that were important for the GUT society.

The blue-grey approach

The overall conception in this approach developed by a group of architects from GUT [29] assumed the revitalisation of the analysed part of the university campus using water as the dominating accent. The conception was based upon the idea of "discovering urban streams", as neither the university society nor the inhabitants of the Wrzeszcz district actually realise that there is a stream flowing underneath the GUT campus. In the XX century, a number of urban streams were channelised, leaving more space for urbanisation. This trend is now being reversed, and urban streams are restored in an attempt to "give more space to water", though the restoration of open channels is in many cases impossible due to the dense development of urban space in the vicinity of the former streams beds.

According to this conception, a large above-ground retention tank of reinforced concrete was planned in the central part of the area (Fig. 3). Gabions with crushed stones were planned to be located at the sidewalls of the tank. According to the project, the total retention capacity of the tank was approx. 2500m^3, the surface area 2082m^2 and average depth was 1.20m. It was assumed that water from the channelised Królewski Stream flowing underground in two pipes would be pumped to feed the retention tank. The constant inflow of 20 l/s, both during the dry and wet periods, was assumed to keep the water depth stable (water table at 10.30m above sea level). The stable depth was required due to the planned recreational function of the tank allowing for rowing in small boats and kayaks. Due to the high variability of the flow rates in the Królewski Stream and to almost "zero" flow during dry periods, it was planned to intermittently use tap water to maintain the assumed water level. A 30cm layer was left in the tank for retention of the surface runoff from the surrounding university area. The surrounding terrain was planned to be completely sealed with stone and concrete slabs. The conception also included constructing a small pavilion adjacent to the retention tank and a pyramid with steep slopes covered partly with grass and with amphitheater-shaped seats made of stone and concrete. Due to concerns regarding the quality of the stream water feeding the retention tank, a vortex settling tank with an oil separator was planned before the discharge.

The blue-grey-green approach

Despite the apparent aesthetic values of the proposed conception (Fig. 3), from the environmental point of view, it had several drawbacks. To list the major cons: complete sealing of the surrounding terrain (increasing surface runoff), concerns for the quality of the retained water (high depth, low mixing, long retention time that was not specified in the project) and the concept of using tap water to maintain the water level in the tank. Finally, the proposed spatial arrangement with the use of concrete and stone slabs would also contribute to creating a local "heat island" effect, that might not be fully mitigated by the water reservoir influence.

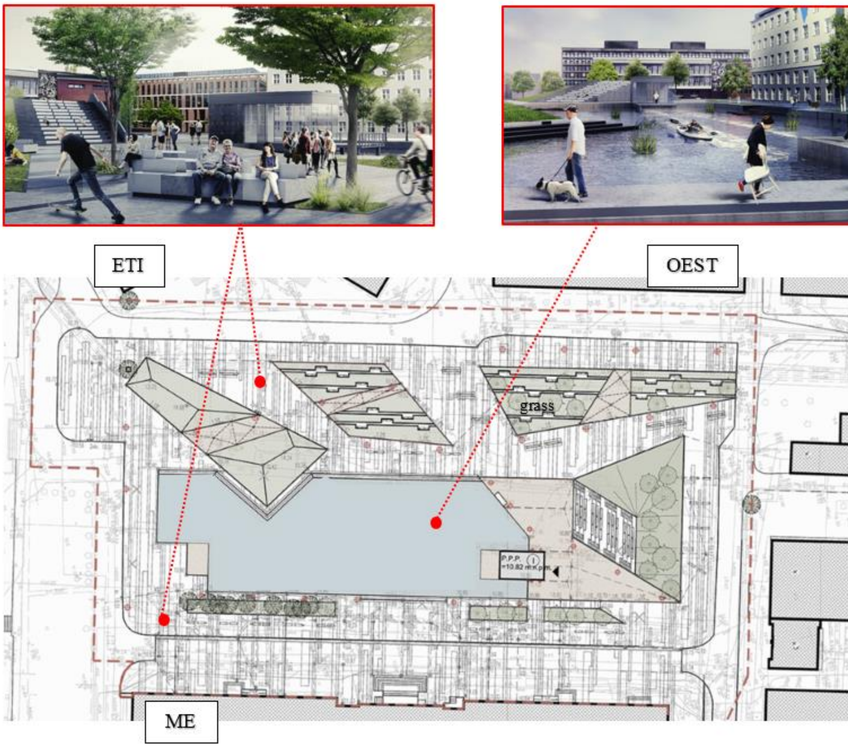

Fig. 3. The blue-grey conception of management the Królewiecki Stream in the analysed part of the GUT campus; abbreviations: ME - Faculty of Mechanical Engineering, OEST - Faculty of Ocean Engineering and Ship Technology, and ETI - Faculty of Electronics, Telecommunications, and Informatics (modified based on *Nyka*) [29]

Thus, the next approach attempted to mitigate the aforementioned problems by introducing some GI elements, however without major changes in the original architectural conception. In particular, the construction of the basic elements: retention tank, pavilion, and pyramid was left unchanged, although some minor amendments were introduced [30].

The primary concern was associated with the poor quality of the waters of the Królewski Stream, specifically during wet periods, when high pollutant concentrations are observed (especially organic matter expressed in BOD_5). Although in the first concept the vortex sedimentation tank with oil separator was included, it could be insufficient to secure the adequate water quality for planned recreation activities. The further deterioration of the water quality due to water stagnation was also likely to occur in the retention tank, especially during warm periods, leading to algal blooms. The recreation function, as well as the prestigious appearance of the area, would suffer on such occasions. Therefore, some further mechanical and biological treatment of retained water, as well as mitigation of potential discharge of pollutants with surface runoff from the adjacent campus area, were proposed, with an attempt to minimise the interference in the original project.

The proposed amendments are presented in the figure 4 and 5. Firstly, the tank was divided into two parts separated by a dyke composed of gabions filled with crushed stones – in other words, a forebay was created before the appropriate tank (open zone).

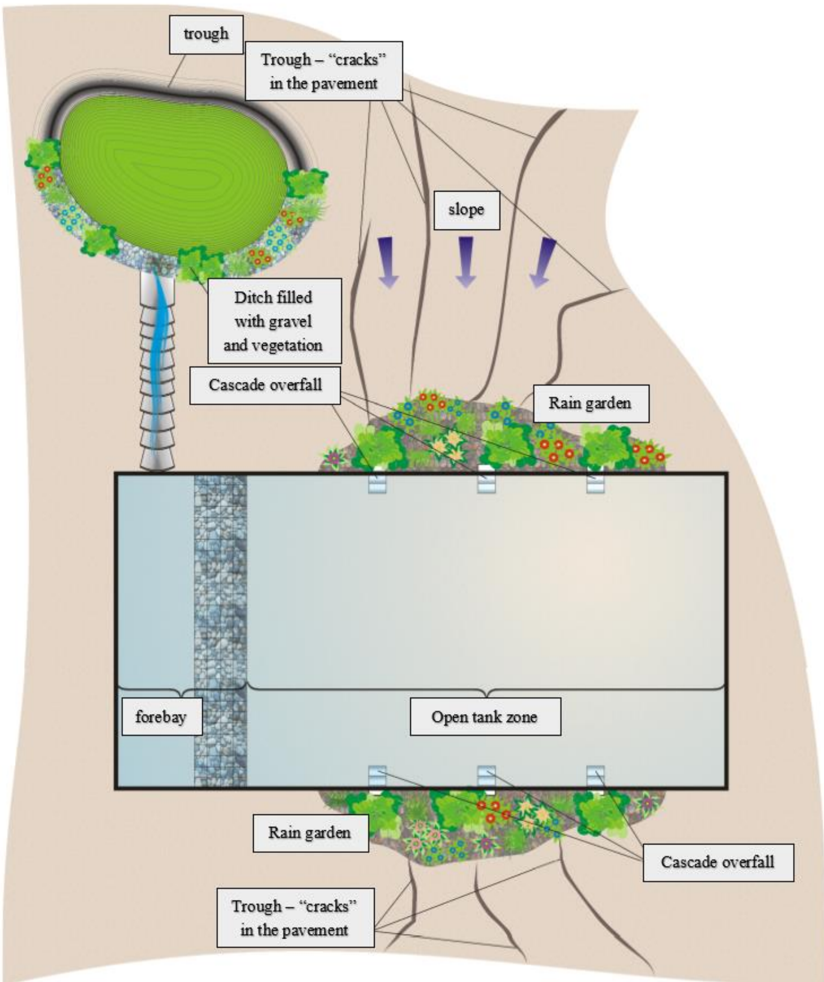

Fig. 4. The blue-grey-green conception of the of management the Królewiecki Stream in the analysed part of the GUT campus (modified based on *Wojciechowska et al.*) [30]

Water purification will be enhanced while it filters through the gabions from the forebay to the open zone. At the same time, sedimentation will be enhanced in the forebay due to decreased flow velocity and the TSS carrying also some load of organics will be entrapped before entering the open tank. *Phragmites, Typha* and other hydrophytes will be planted on the gabions in order to enhance the biogeochemical treatment processes during water filtration through the gabion dyke [31, 32]. In the open tank, 2 floating treatment wetlands (FTW) were also planned as well as baskets with hydrophytes attached to the gabions on the tank sidewalls. Expanding plant roots provide an extensive surface area for the growth of the attached biofilm and entrapment of suspended particulate matter [33, 34]. Wetland macrophytes are characterised by the aerenchyma in their roots and rhizomes, which increases their buoyancy potential as well as helps to improve anaerobic conditions and associated biogeochemical processes. The mechanism of purification performed by a plant submerged system (roots and rhizomes) includes nutrients and metals uptake, biofilms development, extracellular enzyme release, contaminant settling, and binding, as well as suspended matter flocculation enhancement [35].

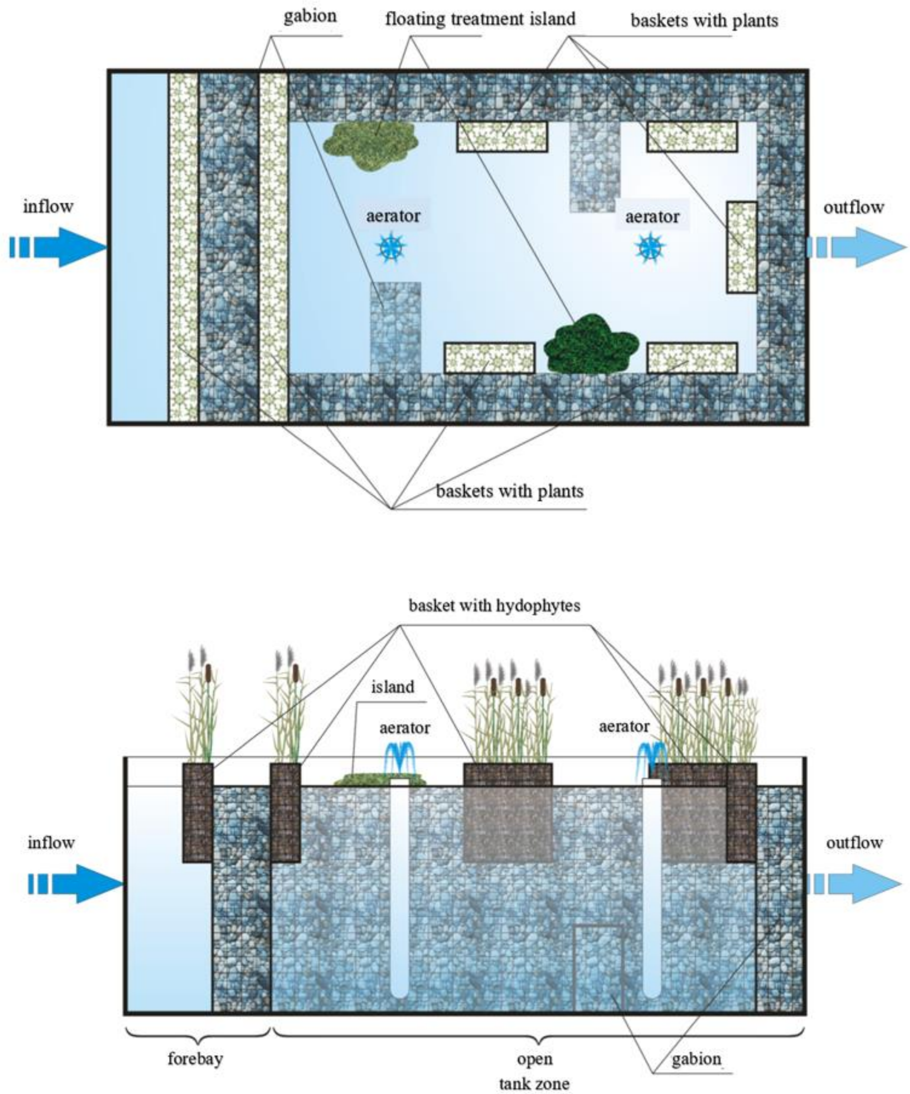

Fig. 5. The amendments proposed in the retention tank within the blue-grey-green approach (modified based on *Wojciechowska et al.*) [30]

Another amendment was the introduction of two shallow zones in an open tank formed by the installation of the gabions attached to the tank's bottom. In these shallow zones, the UV radiation will penetrate the water column providing some "natural" disinfection. The circulation of water in the tank was considered to be very important, and it was forced by aerators installed in the tank. Both circulation and aeration counteract water stagnation and algal blooms. Due to the frequent occurrence of strong winds in the open space between the university buildings, it was not recommended to install fountains with the water sparkling to a high elevation.

Another problem to solve was the quality and quantity of the surface runoff from the completely sealed surrounding area. The runoff quantity was calculated according to the formula (1). The catchment area A is approx. 1.5ha, the runoff coefficient for concrete and stone slabs $= 0.9$. The predicted rainfall was estimated according to the formula (2), as $q = 154L \cdot s^{-1} \cdot ha^{-1}$. The outflow from surface runoff can then be estimated as $Q = 0.9 \cdot 154 \cdot 1.5 = 207.9L \cdot s^{-1}$.

Assuming rainfall duration time $t = 10min$, the volume of surface runoff flowing to the retention tank can be estimated as presented in formula (4):

$$V = Q \cdot t \quad (4)$$

$$V = 207.9 \cdot 60 \cdot 10 = 124740L = approx.\,1247m^3$$

For $t = 50\ min$ the runoff volume would be equal to $623.7\ m^3$ and for $t = 60\ min$ it will be $748.4m^3$.

The retention capacity of the tank can be calculated according with the formula (5):

$$V = h \cdot A \quad (5)$$

where:

$h = 0.3m$ (the depth of retention layer according to the architectural conception), and $A = 2082m^2$, which gives $V = 624.6m^3$.

This shows that the reserve retention volume of the tank is quite big, however, it could appear too small in case of long-lasting rainfalls with higher intensities, that are predicted by the climate change scenarios for summer months. The situation is worsened by the short runoff concentration-time, as water flows on a smooth surface formed by stone slabs or on the steep slopes of the pyramid. The mitigation method assumed establishing some cracks on the uniform sealed surface to enable infiltration of runoff to the ground and the partial reduction of the runoff coefficient value. Moreover, the rain gardens serving as buffer zones adjacent to the retention tank and to the pyramid were proposed to increase runoff concentration-time (as flow slows down on a rough surface covered by shrubs and grass) and to capture some of the pollutants carried by the runoff before it enters the retention tank. The plant buffer zones have proved their efficiency in pollutant discharge with surface runoff in several studies, for instance [36].

The blue-green approach

The third concept presents a completely different approach, as it attempts to propose a holistic approach to the management of stormwater runoff in the revitalised part of the campus with the use of GI elements. The concept was based upon the following assumptions:

- Realising the expectations of the university society
- Involvement of students in the planning process
- Avoiding sealing of the terrain wherever it is possible
- Optimising the ecosystem services of the area (regulating, supporting, provisioning and cultural) [37, 38],
- Enhancement of water treatment
- Functionality (including maintenance)
- Aesthetic appearance

The planning stage was preceded by analysing the results of opinion polls reflecting the expectations of students and university teachers. The results of the opinion poll are presented in figure 6. Among the most important present functions to be included in a future restoration plan, "parking" and "none" were the most popular, gaining 73.3% and 23.3%, respectively. The most pronounced expectation towards the newly planned arrangement of the site was leaving the space for recreation (88.3% of responses). A remarkable accent was put on green spaces, which is in correlation with the fact that at present, there are no green spaces on campus. 91.6% of respondents expected a green space as a new benefit of the restored part of the campus. In the group of university teachers, there was a strong expectation regarding parking spaces, expressed by 88.2% of respondents in this group (only 30.2% of students marked this answer). A positive attitude was expressed towards "rediscovering" the Królewski Stream - 50% of participants marked the answer 5 = ”extremely positive” (65% in the group of students and 11.7% of university teachers) and 31.7% marked 4 = ”positive” (23.3% in the group of students and 52.9% of university teachers). A negative or extremely negative attitude was expressed by only 8.3% of the respondents.

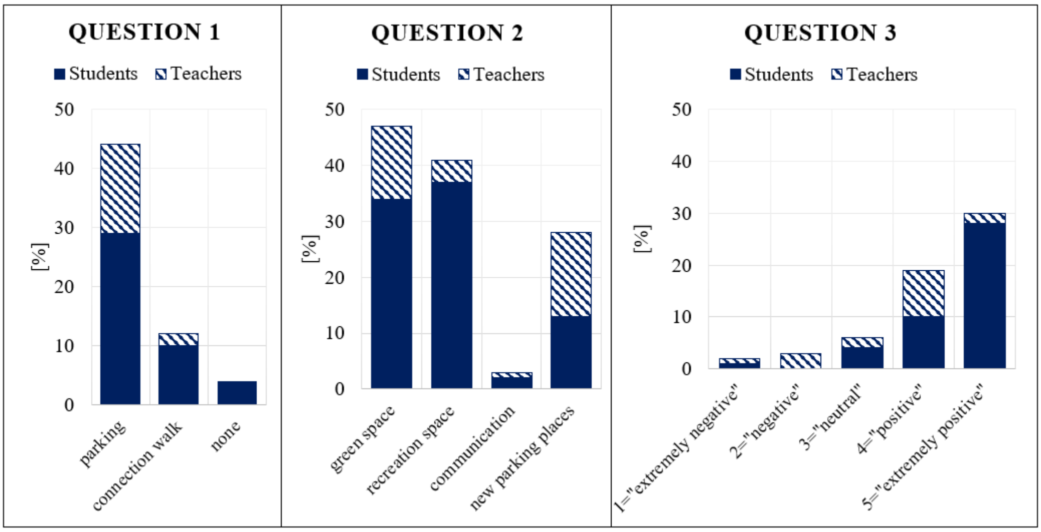

Fig. 6. The results of opinion polls on the 3 posted questions in the questionnaire; Q1: Which of the present functions should be included in the restoration plan?; Q2: What new benefits do you expect from the planned arrangement of the site? Q3: What is your attitude to the restoration of the Królewski Stream on this part of the campus?

After analysing the results of the opinion polls, the concept was prepared (Fig. 7). Following the assumption of involving students in the designing process, the conception was created within a Master's thesis [39] at the Faculty of Civil and Environmental Engineering. The final arrangements of the site will be developed in future theses realised at the Faculty of Architecture.

Parking spaces were left to meet the expectations of university employees, however, the surface cover was changed to permeable, which allows for the reduction of stormwater runoff volume. The surface area of the parking lots will cover approx. $0.17ha$. The runoff reduction due to the change of surface was calculated according to the formula (1), assuming $q = 154L \cdot s^{-1} \cdot ha^{-1}$, $A = 0.17$ ha and runoff coefficient values of $= 0.9$ for sealed surface - formula (6) and $= 0.2$ for permeable surface – formula (7) (Tab.1):

Outflow from sealed surface Q_{bef} (6):

$$Q_{bef} = 0.9 \cdot 154 \cdot 0.17 = 23.56[L \cdot s^{-1}] \quad (6)$$

Outflow from permeable parking surface (Q_{after}) (7):

$$Q_{after} = 0.2 \cdot 154 \cdot 0.17 = 5.24[L \cdot s^{-1}] \quad (7)$$

Outflow from parking lots will be reduced by almost 78 %.

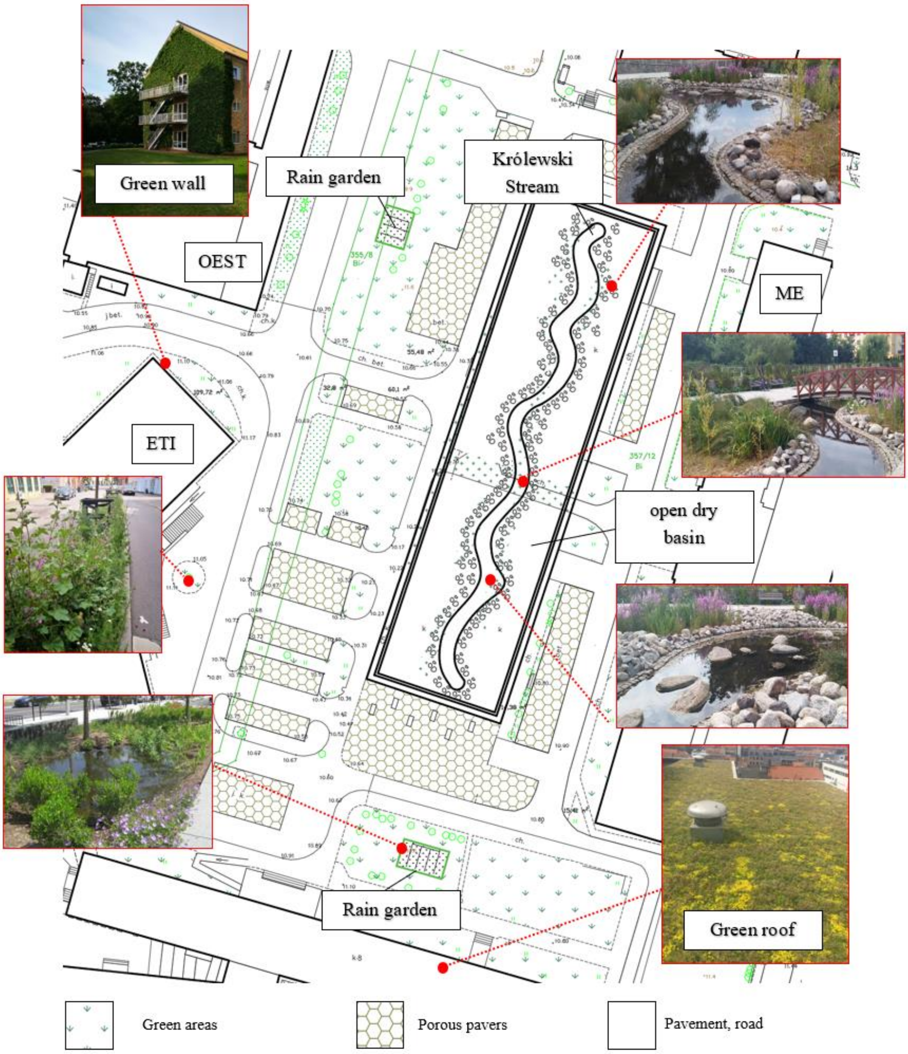

Fig. 7. The blue-green conception of the of management the Królewski Stream in the analysed part of the GUT campus

Two rain gardens, with surface areas of 60m^2 and 50m^2, were proposed to capture the roof runoff from two large buildings of the Faculty of Electronics, Telecommunications and Informatics (ETI) and the Faculty of Ocean Engineering and Ship Technology (OEST). The rain gardens will also receive the surface runoff from surrounding sealed surfaces: roads and pedestrian walks. The rain gardens will provide retention of stormwater runoff, followed by infiltration into the ground. Apart from stormwater runoff regulation as well as groundwater recharge, rain gardens also offer a couple of other ecosystem services, including air pollution mitigation, biodiversity increase, aesthetic values, and reduction of hot summer temperatures due to evapotranspiration. In order to increase the co-benefits offered by GI, it was also proposed to introduce green walls (Fig. 7) at the building ETI. Also, the large flat roof of the old ETI building could be turned into an extensive green roof – a similar approach was adapted during revitalisation of the Augustenborg district in Malmő, Sweden [40, 41]. The elements of Green Infrastructure (rain gardens, green roofs) have strong potential of runoff treatment.

In the central part of the area, a longitudinal vegetated swale will be created, with mild slopes covered with grass and decorative shrubs and flowers. Inside the swale, the bed of the Królewski Stream will be re-created, forming natural-looking meanders. During torrential rainfalls, the swale will offer additional retention volume for capturing the stream's waters and the excess runoff from the university area, while during dry periods, it will be used as a recreation area serving the students and workers of the university, as well as the inhabitants of the surrounding city districts where open green spaces are scarce. The final appearance of the stream bed and the vegetated swale will be inspired by the design of the dry retention tank built on the Karlikowski Stream in Sopot. Similarly to the rain gardens, the vegetated swale offers a number of ecosystem services, with a very important accent put on its educational value due to the fundamental function of the area. The vegetation zones adjacent to Królewski Stream bed will contribute to water purification (with regard both to the surface runoff and to the stream waters). Additional retention areas in the middle run of the Królewski Stream will also contribute to the flooding protection of this part of the Wrzeszcz district.

Comparison of the outflow for three conceptions

The comparison of the outflow from the campus catchment for analysed conceptions is presented in figure 8. We observed that blue-grey-green approach allowed for 32% of outflow reduction in comparison to the original concept of stormwater management. The highest outflow reduction was observed for the third conception, which allowed for up to 52% reduction of outflow from the analyzed catchment. Designing in line with green infrastructure by introducing such treatments as permeable parking lots and green roofs resulted in a decrease in outflow from 98.4L·s^{-1} to 54.2L·s^{-1} in total.

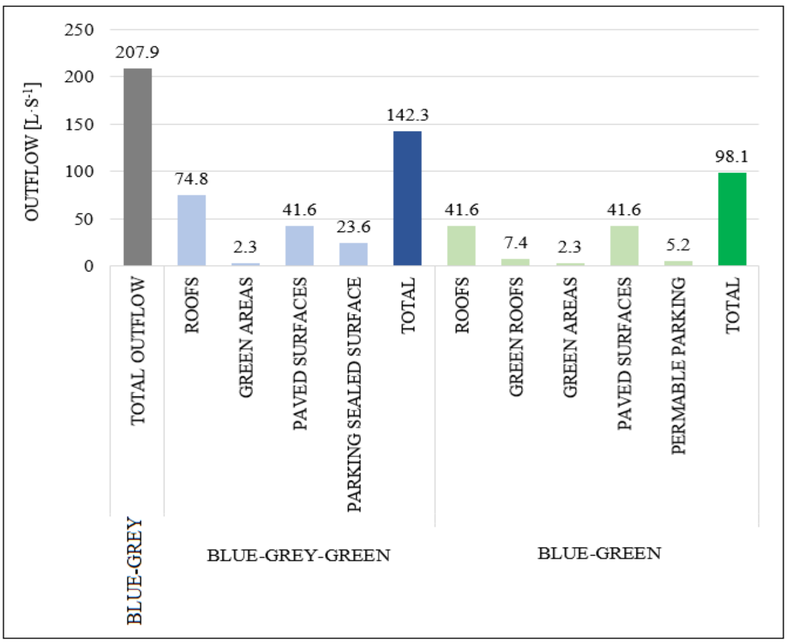

Fig. 8. The comparative analysis of the outflow from the GUT campus catchment in L·s^{-1} for three approaches: blue-grey, blue-grey-green, and blue-green

Analyses of benefits and drawbacks of the three conceptions

In the competition for land in densely populated urban space, there could be many conceptions of spatial development inter-linked to stormwater management. The selection of the best solution for each specific site may turn out to be a difficult task since different criteria seem to be equally important. Probably, to fully compare all options and decide which one is the best, multi-parameter optimisation and/or advanced models would be a good choice [8, 42-44], though requiring adequate tools and time needed for building, fitting and testing of the model. Thus, more simple approaches can also provide comparisons useful in the decision-making process. Here, we compared the three options basing on the Water Sensitive Urban Design (WSUD) evaluation objectives proposed by *Hoyer et al.* [45]. They listed five criteria that need to be fulfilled for successful implementation of decentralised stormwater management: water sensitivity, aesthetics, functionality, usability, and public perception and acceptance. Water sensitivity is defined as bringing urban water management closer to the natural water cycle. Aesthetics includes visual appearance as well as integration into the surrounding area. Functionality is associated with appropriate design (adapted to local conditions and the intended use), maintenance requirements and the ability to adapt to uncertain and changing conditions, while "usability" means that the proposed solutions should be "used to create places that are usable for recreation and/or nature conservation purposes" [45]. The last principle requires public involvement and meeting public demands as well as acceptable costs (comparable or lower to the costs of standard, "grey" solutions). In Table 2, the three concepts proposed for the analysed site were evaluated according to the principles adapted from *Hoyer et al.* [45] with small amendments. Firstly, we did not analyse the costs. Secondly, we changed "public involvement" to "public involvement and meeting public expectations". We also added a new category "Water treatment" in order to emphasize this function which is of high relevance in the analysed area.

Table 2. Evaluation of three conceptions of development of part of GUT campus including restoration of the Królewski Stream

Principle	Blue-grey	Blue-grey-green	Blue-green
Water sensitivity	-	+/-	+
Aesthethic benefit	+	+	+
Integration in the surrounding area	+	+	+/-
Appropriate design	+/-	+/-	+
Maintenance	-	+/-	+/-
Adaptability	-	+/-	+
Usability	+/-	+/-	+
Water treatment	-	+/-	+
Public involvement and meeting public expectations	-	-	+

The positive aspects of the blue-grey conception, apart from the aesthetic benefits and integration in the surrounding area, are creating recreational function and retention of the surface runoff and of the stream waters during torrential rainfalls. The retention tank in the middle-run of the Królewski Stream can help to protect the downstream catchment from flooding. The criteria "appropriate design" and "usability" are discussable. According to the usability criterion, the intended recreational function of the area is well developed, however, the concrete retention tank and sealed surface nearby will not contribute to nature conservation and biodiversity increase. The appropriate design also has "pros" and "cons". The main concern is the high depth of the retention tank that can cause water stagnation and deterioration of its quality as well as the deposition of sediments that need to be periodically removed, which generates maintenance problems and additional costs. Moreover, due to the depth of the tank, some security measures should be undertaken to avoid accidents. The sealed surface built of stone slabs surrounding the tank can also create danger as it becomes slippery when wet. Taking these aspects into account, the maintenance criterion was negatively evaluated. The minus in the "water sensitivity" category was based on the increase of surface runoff due to surface sealing, and the concept of additional supply with potable water to maintain the water depth. The mixing of clean water with surface water of potentially poor quality and with the surface runoff is unacceptable from an environmental point of view, and would also generate high costs. The proposed conception also doesn't seem to be easily adaptable to changing conditions including climate change scenarios predicting alternate events of cloudbursts and periods of urban droughts [46]. Finally, the concept did not attempt to address public expectations, for example leaving space for parking.

The blue-grey-green solution attempted to fix some of the problems arising from the previous conception, in terms of water sensitivity, maintenance and adaptability, however the final result can be judged as ambiguous. The major obstacle was the requirement of minimal integration in the original conception. Therefore, the emphasis was placed in particular on the quality of the water in the tank and possible threats related to the tank designed in the blue-grey approach.

The last solution focused on the implementation of GI units into the existing area. In Table 2 it received pluses in each category, apart from integration in the surrounding area (+/-) and maintenance. Our hesitation in these two categories concerned the parking lots included in this conception. The parking places are unambiguously useful and functional, as it was reflected in the opinion polls. Besides, the permeable surface allows for decreasing of the surface runoff. On the other hand, the permeable surface requires proper maintenance (jet washing, vacuum cleaning) to maintain its properties [47]. Moreover, the aesthetic benefits and integration of parking lots in the campus area are lower. Hopefully, the final aesthetic appearance of the whole restored area with the Królewski Stream bed flowing in a vegetated swale will compensate the less representative parking lots. The strong point of the blue-green solution is the positive impact on the water quality and treatment of the runoff from the campus area in the GI units (rain gardens, swale). It should be also emphasised, when comparing the three presented approaches, that GI has been proved to possess much stronger potential for mitigation of the urban heat island effect then the "blue" solutions (urban stream and water reservoirs) [48].

Green Infrastructure versus traditional "grey" infrastructure: the considerations on social perception

The analysis based upon criteria proposed by *Hoyer et al.* [45], although simple and useful, shows that comparison of different options of site development may appear controversial in some aspects. This applies for the example to aesthetic value, which can be interpreted in different ways by different people, depending on their taste, age, cultural background, and personal predispositions. Some people would prefer the spatial order and prestigious appearance of the grey-blue solution, while the other would like to experience more contact with nature or at least with substituting Green Infrastructure units.

Alves et al. [8] noticed that grey solutions of stormwater management still seem to have stronger feedback – including well-known technical solutions, administrative and legislative support as well as social acceptance, as in most cities people are used to the standard of technical infrastructure that they know from their early years. Another important aspect is the fact, that people may not fully realise how a single GI unit contributes to flooding control and what co-benefits it brings in the catchment scale [44, 49].

On the other hand, GI brings multiple and important co-benefits and functions for the society, as it was indicated by Pedersen et al. [50] who analysed the cultural ecosystem services of the wetland sites. Seemingly, once the GI solutions are introduced for the first time, they have the potential of gaining acceptance of the society. To make the GI implementation successful, social involvement is desired at every stage of conception development. A well-known and very good example of a sustainable project of WSUD is the district of Augustenborg in Malmő, Sweden [40, 41].

In our considerations regarding the three options of development of part of the GUT campus, including the restoration of the Królewski Stream, there seems to be one more important aspect, that has not been mentioned before and this is the educational role of the site. This creates a unique opportunity and at the same time responsibility for creating a solution that could be preserved in the minds of the young generation as a model one. As GI is based on a concept that an urban area with healthy ecosystems can actively mitigate urban growth and climate change [51] it is definitely the solution that should be popularised.

Conclusions

Three different concepts of stormwater management at part of the GUT campus were considered, presenting the evolutionary approach to the issue of urban stormwater management. Each of the subsequent conceptions was better than the preceding one, starting with the blue grey solution, through the blue-grey-green conception were only small "green accents" were included, to the final blue-green option, basing on GI units. The analyses of the three options indicate that the last, blue-green approach offered more benefits than two other concepts, though the original architectural conception had incontestable aesthetic value. The blue-green solution received pluses in 7 out of 9 categories and "+ / -" in the remaining two. At the same time the original, blue-grey conception received 5 minuses and only 2 pluses, while the blue-grey-green conception, though ranked higher, still had one minus and was ranked "+ / -" in 6 categories. The final score of the blue-grey-green approach, which attempted to fix some problems of the original conception without making huge changes, shows that this attempt failed. It becomes evident that using of any "intermediate" approach between "grey" and "green" infrastructure is useless. The results show that GI has the potential to replace conventional grey solutions and to increase a city's resilience and adaptability to flash floods, important in the light of prospective climate change. In the design process, the co-benefits should be optimised under the ecosystem services paradigm to gain "as much as possible" from each newly developed urban area. Social involvement in the process is highly relevant to achieve fully functional and widely acceptable solutions. Future research should concentrate on the preparation of simple and reliable tools allowing for comparison between various development conceptions.

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